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PNL-6415 Rev. 7

UC-600

Hanford Site National Environmental Policy Act (NEPA) Characterization

C. E. Cushing, Editor

September 1995

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161

This document was printed on recyled paper.

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Preface

Many NEPA compliance documents have been prepared and are being prepared by Site contractors for the U.S. Department of Energy (DOE), and examination of these documents reveals inconsistencies in the data presented and the method of presentation. Thus, it seemed necessary to prepare a consistent description of the Hanford Site environment to be used in preparing Chapter 4.0 of environmental impact statements and other site-related National Environmental Policy Act (NEPA) documentation. This document describes the Hanford Site environment (Chapter 4.0) and contains data in Chapters 5.0 and 6.0 that will assist users in the preparation of NEPA-related documents. The material in Chapter 5.0 is a guide to the models used, including critical assumptions incorporated in these models in previous Hanford NEPA documents. The user will have to select those models appropriate for the proposed action. Chapter 5.0 was not revised in Revision 7. Chapter 6.0 is essentially a definitive NEPA Chapter 6.0, which describes applicable federal and state laws and regulations. People preparing environmental assessments and environmental impact statements should also be cognizant of the document entitled Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements published by the DOE Office of NEPA Oversight in May 1993 (DOE 1993).

In this document, a complete description of the environment is presented in Chapter 4.0 without extensive tabular data. For these data, sources are provided. Most subjects are divided into a general description of the characteristics of the Hanford Site, followed by site-specific information, where available, on the 100, 200, 300, and other areas. This division will allow a person requiring information to go immediately to those sections of particular interest. However, specific information on each of these separate areas is not always complete or available. In this case, the general Hanford Site description should be used.

To enhance the usability of the document, a copy of the text is available on an IBM PC diskette in WordPerfect 5.1 on request to C. E. Cushing at (509) 376-9670. Macintosh diskettes are also available (WordPerfect). The document is also available electronically at http://wwwi.pnl.gov/ which is the homepage of the Pacific Northwest Laboratory.

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Suggested citation for this document: Cushing, C. E. (Ed.). 1995. Hanford Site National Environmental Policy Act (NEPA) Characterization. PNL-6415, Rev. 7, Pacific Northwest Laboratory, Richland, Washington.

Summary

This seventh revision of the Hanford Site National Environmental Policy (NEPA) Characterization presents current environmental data regarding the Hanford Site and its immediate environs. This information is intended for use in preparing Site-related NEPA documentation.

Chapter 4.0 summarizes up-to-date information on climate and meteorology, geology, hydrology, environmental monitoring, ecology, history and archaeology, socioeconomics, land use, and noise levels prepared by Pacific Northwest Laboratory (PNL) staff. More detailed data are available from reference sources cited or from the authors.

Chapter 5.0 was not updated from the sixth revision (1994). It describes models, including their principal underlying assumptions, that are to be used in simulating realized or potential impacts from nuclear materials at the Hanford Site. Included are models of radionuclide transport in groundwater and atmospheric pathways, and of radiation dose to populations via all known pathways from known initial conditions.

The updated Chapter 6.0 provides the preparer with the federal and state regulations, DOE Orders and permits, and environmental standards directly applicable to the NEPA documents on the Hanford Site, following the structure of Chapter 4.0.

No conclusions or recommendations are given in this report. Rather, it is a compilation of information on the Hanford Site environment that can be used directly by Site contractors. This information can also be used by any interested individual seeking baseline data on the Hanford Site and its past activities by which to evaluate projected activities and their impacts.

Contents

Figures

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4.0 Affected Environment

The U.S. Department of Energy's (DOE's) Hanford Site lies within the semiarid Pasco Basin of the Columbia Plateau in southeastern Washington State (Figure 4.0-1). The Hanford Site occupies an area of about 1450 km^2 ($\sim$560 mi^2) north of the confluence of the Yakima River with the Columbia River. The Hanford Site is about 50 km (30 mi) north to south and 40 km (24 mi) east to west. This land, with restricted public access, provides a buffer for the smaller areas currently used for storage of nuclear materials, waste storage, and waste disposal; only about 6% of the land area has been disturbed and is actively used. The Columbia River flows through the northern part of the Hanford Site and, turning south, forms part of the Site's eastern boundary. The Yakima River runs near the southern boundary and joins the Columbia River below the city of Richland, which bounds the Hanford Site on the southeast. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the southwestern and western boundaries. The Saddle Mountains form the northern boundary of the Hanford Site. Two small east-west ridges, Gable Butte and Gable Mountain, rise above the plateau of the central part of the Hanford Site. Adjoining lands to the west, north, and east are principally range and agricultural land. The cities of Richland, Kennewick, and Pasco (Tri-Cities) constitute the nearest population center and are located southeast of the Hanford Site.

Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund), the Hanford Site encompasses more than 1500 waste management units and 4 groundwater contamination plumes that have been grouped into 79 operable units. Each unit has complementary characteristics of such parameters as geography, waste content, type of facility, and relationship of contaminant plumes. This grouping into operable units allows for economies of scale to reduce the cost and number of characterization investigations and remedial actions that will be required for the Hanford Site to complete environmental clean-up efforts (WHC 1989). The 79 operable units have been aggregated into four areas: 22 in the 100 Area, 43 in the 200 Areas, 5 in the 300 Area, and 4 in the 1100 Area. There are an additional 5 units in the 600 Area Isolated Waste Site Area (WHC 1989). Those persons contemplating NEPA-related activities on the Hanford Site should be aware of the existence and location of the various operable units. Current maps showing the locations of the operable units can be obtained from the environmental restoration contractor.

4.1 Climate and Meteorology

The Hanford Site is located in a semiarid region of southeastern Washington State. The Cascade Mountains, beyond Yakima to the west (see Figure 4.2-1 for a location of the Cascade Mountains), greatly influence the climate of the Hanford area by means of their "rain shadow" effect; this mountain range also serves as a source of cold air drainage, which has a considerable effect on the wind regime on the Hanford Site.

Climatological data are available for the Hanford Meteorological Station (HMS), which is located between the 200 East and 200 West Areas. Data have been collected at this location since 1945, and a summary of these data through 1993 has been published by Hoitink and Burk (1994). Data from the HMS are representative of the general climatic conditions for the region and describe the specific climate of the 200 Area Plateau. Local variations in the topography of the Hanford Site may cause

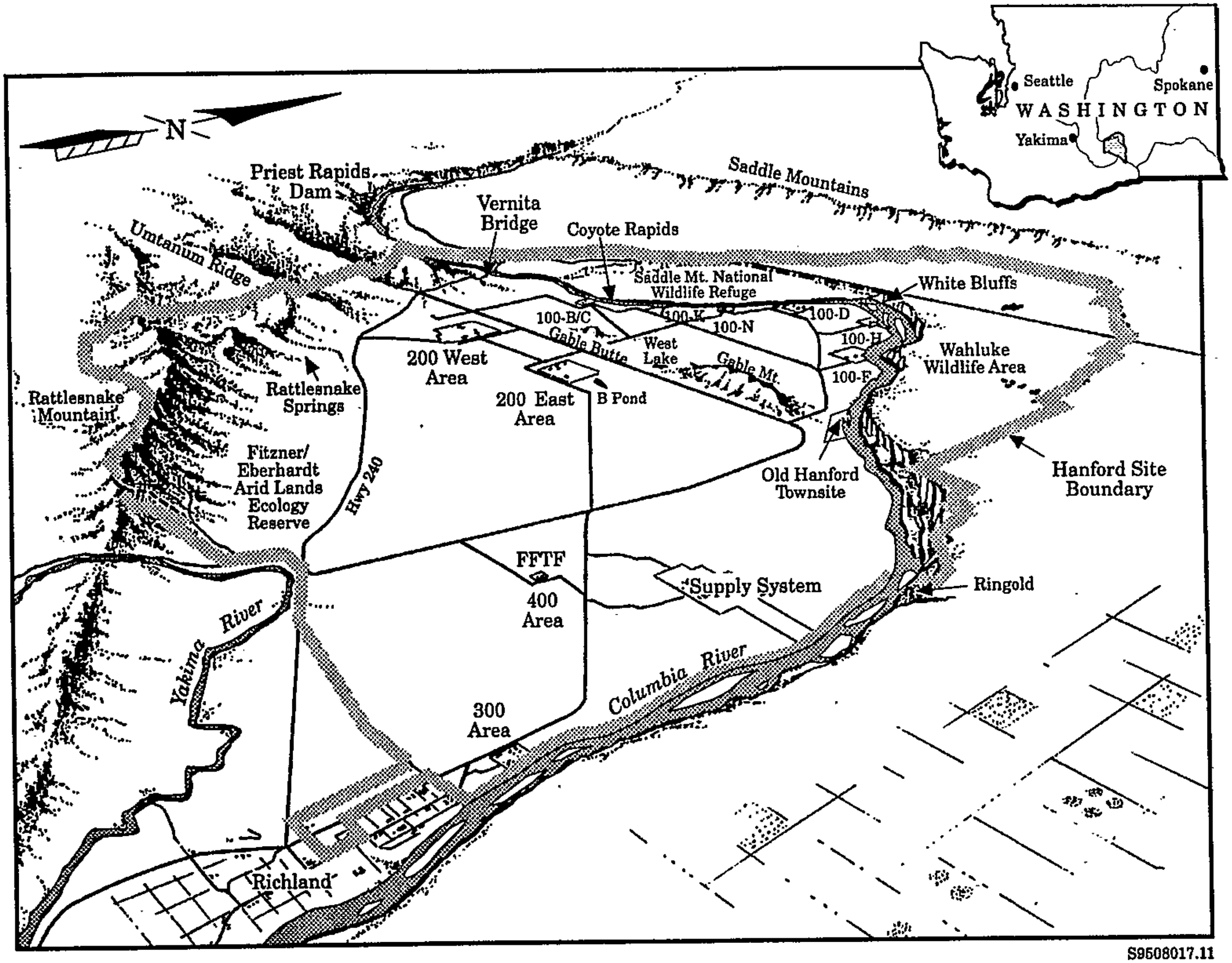

Figure 4.0-1. DOE's Hanford Site and surrounding area.

some aspects of climate at portions of the Hanford Site to differ significantly from those of the HMS. For example, winds near the Columbia River are different than those at the HMS. Similarly, precipitation along the slopes of the Rattlesnake Hills differs from that at the HMS.

4.1.1 Wind

Wind data are collected at the HMS at the surface (2.1 m, ~7 ft above ground) and at the 15.2-, 30.5-, 61.0-, 91.4-, and 121.9-m levels of a 125-m (410-ft) tower. Three 60-m (200-ft) towers, with wind-measuring instrumentation at the 10-, 25-, and 60-m levels, are located at the 300, 400, and 100-N Areas. In addition, wind instruments on twenty-four 9.1-m (30-ft) towers distributed on and around the Hanford Site (Figure 4.1-1) provide supplementary data for defining wind patterns. Instrumentation on each of the towers is described in Table 4.1-1.

Prevailing wind directions on the 200 Area Plateau are from the northwest in all months of the year (Figure 4.1-2). Secondary maxima occur for southwesterly winds. Summaries of wind direction indicate that winds from the northwest quadrant occur most often during the winter and summer. During the spring and fall, the frequency of southwesterly winds increases with a corresponding decrease in northwest flow. Winds blowing from other directions (e.g., northeast) display minimal variation from month to month.

Monthly and annual joint-frequency distributions of wind direction versus wind speed for the HMS are given by Hoitink and Burk (1994). Monthly average wind speeds are lowest during the winter months, averaging 10 to 11 km/h (6 to 7 mi/h), and highest during the summer, averaging 14 to 16 km/h (8 to 10 mi/h). Wind speeds that are well above average are usually associated with southwesterly winds. However, the summertime drainage winds are generally northwesterly and frequently reach 50 km/h (30 mi/h). These winds are most prevalent over the northern portion of the Hanford Site.

4.1.2 Temperature and Humidity

Temperature measurements are made at the 0.9-, 9.1-, 15.2-, 30.5-, 61.0-, 76.2-, 91.4-, and 121.9-m levels of the 125-m (410-ft) tower at the HMS. As of March 1995, temperatures are also measured at the 2-m (~6.5-ft) level on the twenty-four 9.1-m (30-ft) towers located on and around the Hanford Site.. The three 60-m (200-ft) towers have temperature-measuring instrumentation at the 2-, 10-, and 60-m (~6.5-, 33-, and 200-ft) levels. The temperature data from the 9.1- and 60-m (30- and 200-ft) towers are telemetered to the HMS.

Monthly averages and extremes of temperature, dew point, and humidity are contained in Hoitink and Burk (1994). Ranges of daily maximum temperatures vary from normal maxima of 2°C (35°F) in late December and early January to 35°C (95°F) in late July. There are, on the average, 51 days during the summer months with maximum temperatures ≥32°C (90°F) and 12 days with maxima greater than or equal to 38°C (100°F). From mid-November through early March, minimum temperatures average ≤0°C (32°F), with the minima in late December and early January averaging -6°C (21°F). During the winter, there are, on average, 3 days with minimum temperatures ≤-18°C (~0°F); however, only about one winter in two experiences such temperatures. The record maximum temperature is 45°C (113°F), and the record minimum temperature is -31°C (-23°F). For

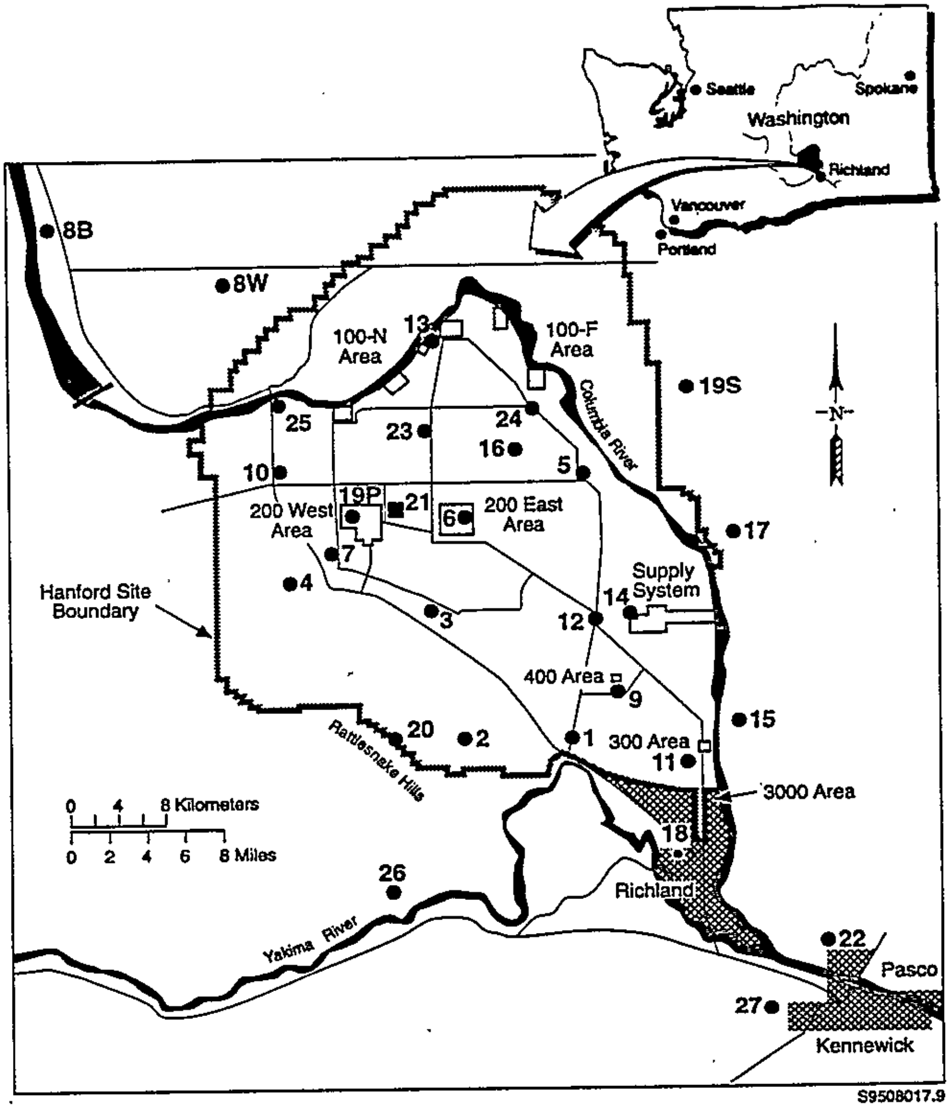

Figure 4.1-1. Hanford Meteorological Monitoring Network.

Station No.	Station Name	Station No.	Station Name
1	Prosser Barricade	14	Supply System
2	EOC	15	Franklin County
3	Army Loop Road	16	Gable Mountain
4	Rattlesnake Springs	17	Ringold
5	Edna	18	Richland Airport
6	200 East	19P	Plutonium Finishing Plant
7	200 West	19S	Sagehill (inactive)
8B	Beverly	20	Rattlesnake Mountain
8W	Wahluke Slope (inactive)	21	Hanford Meteorological Station (125 m)
9	FFTF (60 m)	22	Tri-Cities Airport
10	Yakima Barricade	23	Gable West
11	300 Area (60 m)	24	100-F
12	Wye Barricade	25	Vernita
13	100-N (60 m)	26	Benton City
		27	Vista

NOTE: All network stations are 9.1 m (~30 ft) unless otherwise indicated.

Table 4.1-1. Station numbers, names, and instrumentation for each Hanford Meteorological Monitoring Network site.

Site Number	Site Name	Instrumentation
1	Prosser Barricade	WS, WD, T, P
2	EOC	WS, WD, T, P
3	Army Loop Road	WS, WD, T, P
4	Rattlesnake Springs	WS, WD, T, P
5	Edna	WS, WD, T
6	200 East	WS, WD, T, P, AP
7	200 West	WS, WD, T, P
8B	Beverly	WS, WD, T, P
8W*	Wahluke Slope	WS, WD, T, P
9	FFTF (60 m)	WD, T, TD, DP, P, AP
10	Yakima Barricade	WS, WD, T, P, AP
11	300 Area (60 m)	WS, WD, T, TD, DP, P, AP
12	Wye Barricade	WS, WD, T, P
13	100-N (60 m)	WS, WD, T, TD, DP, P, AP
14	Supply System	WS, WD, T, P
15	Franklin County	WS, WD, T
16	Gable Mountain	WS, WD, T
17	Ringold	WS, WD, T
18	Richland Airport	WS, WD, T, AP
19P	Plutonium Finishing Plant	WS, WD, T, AP
19S*	Sagehill	WS, WD, T
20	Rattlesnake Mountain	WS, WD, T, P
21	Hanford Meteorology Station (125 m)	WS, WD, T, P, AP
22	Tri-Cities Airport	WS, WD, T, P
23	Gable West	WS, WD, T
24	100-F	WS, WD, T, P
25	Vernita Bridge	WS, WD, T
26	Benton City	WS, WD, T, P, AP
27	Vista	WS, WD, T, P
28	Roosevelt	WS, WD, T, P

Legend:
- WS - Wind speed
- WD - Wind direction
- T - Temperature
- TD - Temperature difference
- DP - Dewpoint temperature
- P - Precipitation
- AP - Atmospheric pressure

* Station no longer active.

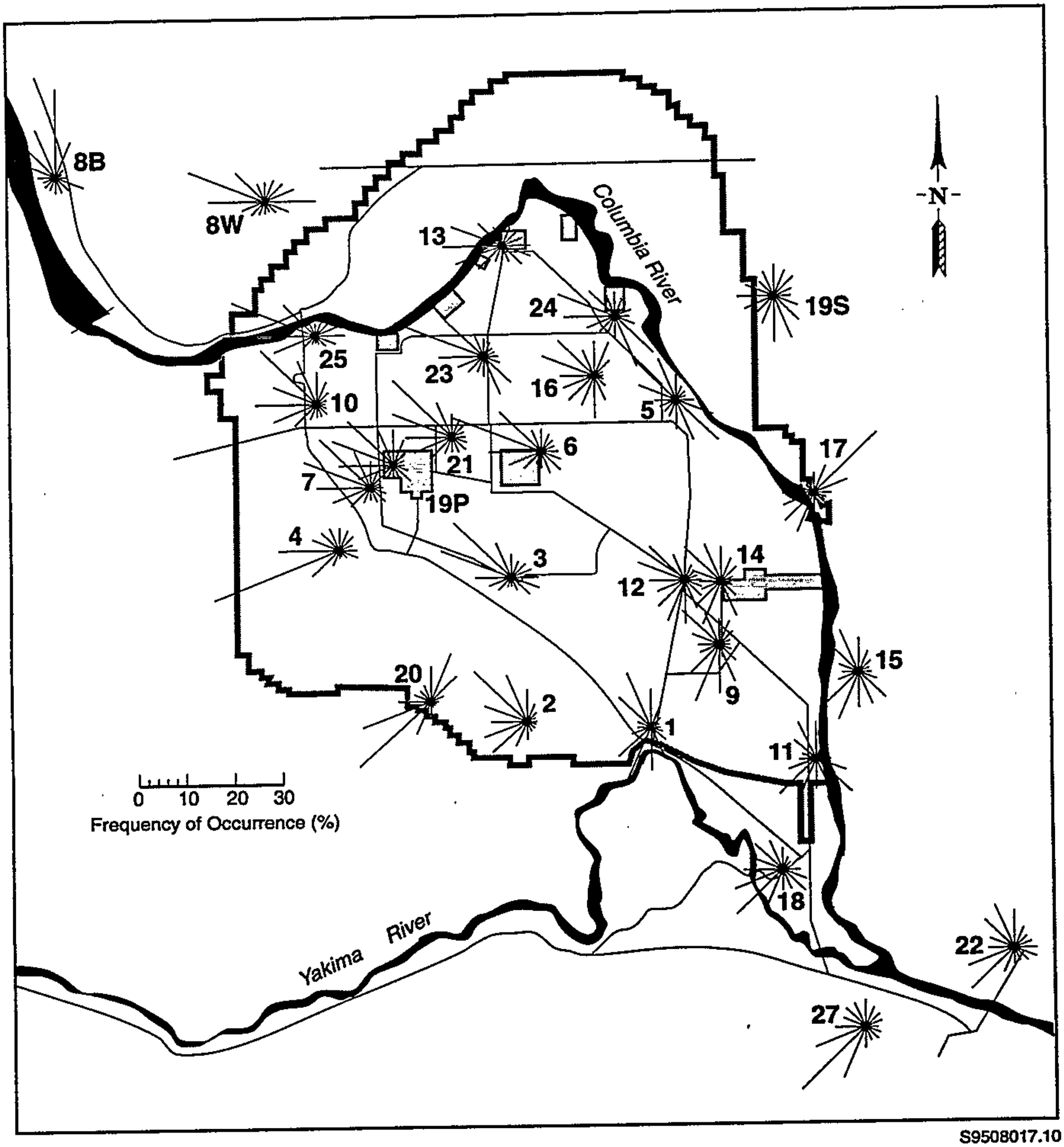

Figure 4.1-2. Wind roses (at 10 m) for the Hanford Meteorological Monitoring Network, 1979 to 1994. The point of each rose represents the direction from which the winds come.

the period 1946 through 1993, the average monthly temperatures range from a low of -0.9°C (30°F) in January to a high of 24.6°C (76°F) in July. During the winter, the highest monthly average temperature at the HMS was 6.9°C (44°F) in February, and the record lowest was -11.1°C (12°F) during January. During the summer, the record maximum monthly average temperature was 27.9°C (82°F) in July, and the record lowest was 17.2°C (63°F) in June.

Relative humidity/dew point temperature measurements are made at the HMS and at the three 60-m (200-ft) tower locations. The annual average relative humidity at the HMS is 54%. It is highest during the winter months, averaging about 75%, and lowest during the summer, averaging about 35%. Wet bulb temperatures >24°C (75°F) had not been observed at the HMS before 1975; however, on July 8, 9, and 10 of that year, there were seven hourly observations with wet bulb temperatures ≥24°C (75°F).

4.1.3 Precipitation

Precipitation measurements have been made at the HMS since 1945. Average annual precipitation at the HMS is 16 cm (6.3 in.). Most precipitation occurs during the winter, with more than half of the annual amount occurring from November through February. Days with >1.3 cm (0.51 in.) precipitation occur less than 1% of the year. Rainfall intensities of 1.3 cm/h (0.51 in./h) persisting for 1 hour are expected once every 10 years. Rainfall intensities of 2.5 cm/h (1 in./h) for 1 hour are expected only once every 500 years. Winter monthly average snowfall ranges from 0.8 cm (0.32 in.) in March to 14.5 cm (6 in.) in December. The record monthly snowfall of 62 cm (24 in.) occurred in February 1916. The seasonal record snowfall of 142 cm (56 in.) occurred during the winter of 1992-1993. Snowfall accounts for about 38% of all precipitation from December through February.

Climatological precipitation measurements have also been made on the Fitzner/Eberhardt Arid Lands Ecology Reserve (ALE) on the northeast slope of the Rattlesnake Hills (Stone et al. 1983).

4.1.4 Fog and Visibility

Fog has been recorded during every month of the year at the HMS; however, 95% of the occurrences are from November through February, with less than 1% from April through September (Table 4.1-2). The average number of days per year with fog (visibility less than or equal to 9.6 km or 6 mi) is 46, and with dense fog (visibility less than or equal to 0.4 km or 0.25 mi), 24. The greatest number of days with fog was 84 days in 1985-1986, and the least, 22 in 1948-1949; the greatest number of days with dense fog was 42 days in 1950-1951, and the least, 9 days in 1948-1949. The greatest persistence of fog was 114 hours (December 1985), and the greatest persistence of dense fog was 47 hours (December 1957).

Other phenomena causing restrictions to visibility (i.e., visibility ≤9.6 km [6 mi]) include dust, blowing dust, and smoke from field burning. There are few such days; an average of 5 day/yr have dust or blowing dust and <1 day/yr has reduced visibility from smoke.

Table 4.1-2. Number of days with fog by season.

Category	Winter	Spring	Summer	Autumn	Total
Fog	32	2	$\leq$1/2	12	46
Dense fog	17	1	$\leq$1/2	6	24

4.1.5 Severe Weather

High winds are also associated with thunderstorms. The average occurrence of thunderstorms is 10 per year. They are most frequent during the summer; however, they have occurred in every month. The average winds during thunderstorms come from no specific direction. Estimates of the extreme winds, based on peak gusts observed from 1945 through 1980, are given in Stone et al. (1983) and are shown in Table 4.1-3. Using the National Weather Service criteria for classifying a thunderstorm as "severe" (i.e., hail with a diameter ≥20mm [1 in.] or wind gusts of ≥93 km/h [58 mi/h]), only 1.9% of all thunderstorm events observed at the HMS have been "severe" storms, and all met the criteria based on wind gusts.

Tornadoes are infrequent and generally small in the northwest portion of the United States. Grazulis (1984) lists no violent tornadoes for the region surrounding Hanford (DOE 1987). The HMS climatological summary (Stone et al. 1983) and the National Severe Storms Forecast Center database list 22 separate tornado occurrences within 161 km (100 mi) of the Hanford Site from 1916 through August 1982. Two additional tornadoes have been reported since August 1982.

Using the information in the preceding paragraph and the statistics published in Ramsdell and Andrews (1986) for the 5° block centered at 117.5° west longitude and 47.5° north latitude (the area in which the Hanford Site is located), the expected path length of a tornado on the Hanford Site is 7.6 km (5 mi), the expected width is 95 m (312 ft), and the expected area is about 1.5 km^2 (1 mi^2). The

Table 4.1-3. Estimates of extreme winds at the Hanford Site.

	Peak gusts (km/h)	
Return period (yr)	15.2 m above ground	61 m above ground
2	97	109
10	114	129
100	137	151
1000	159	75

estimated probability of a tornado striking a point at Hanford, also from Ramsdell and Andrews (1986), is 9.6×10^{-6}/yr. The probabilities of extreme winds associated with tornadoes striking a point can be estimated using the distribution of tornado intensities for the region. These probability estimates are given in Table 4.1-4.

4.1.6 Atmospheric Dispersion

Atmospheric dispersion is a function of wind speed, duration and direction of wind, atmospheric stability, and mixing depth. Dispersion conditions are generally good if winds are moderate to strong, if the atmosphere is of neutral or unstable stratification, and if there is a deep mixing layer. Good dispersion conditions associated with neutral and unstable stratification exist about 57% of the time during the summer. Less favorable dispersion conditions may occur when the wind speed is light and the mixing layer is shallow. These conditions are most common during the winter when moderately to extremely stable stratification exists about 66% of the time. Less favorable conditions also occur periodically for surface and low-level releases in all seasons from about sunset to about an hour after sunrise as a result of ground-based temperature inversions and shallow mixing layers. Mixing-layer thicknesses have been estimated at the HMS using remote sensors. The variations in mixing layer described previously are summarized in Table 4.1-5.

Occasionally there are extended periods of poor dispersion conditions associated with stagnant air in stationary high-pressure systems that occur primarily during the winter months. Stone et al. (1972) estimated the probability of extended periods of poor dispersion conditions. The probability of an inversion period extending more than 12 hours varies from a low of about 10% in May and June to a high of about 64% in September and October. These probabilities decrease rapidly for durations of >12 hours. Table 4.1-6 summarizes the probabilities associated with extended surface-based inversions.

Annual average atmospheric diffusion factors (X/Q') have been computed at the Skagit- Hanford Site (northwest of the Wye Barricade) and the 200 East Area using 1983 through 1987 meteorological data. These diffusion factors are presented in Tables 4.1-7 through 4.1-9 as a function of direction and distance from the measurement point. Table 4.1-7, for the Skagit-Hanford Site, shows ground-level

Table 4.1-4. Estimate of the probability of extreme winds associated with tornadoes striking a point at Hanford.[a]

Wind speed (km/h)	Probability per year
100	2.6×10^{-6}
200	6.5×10^{-7}
300	1.6×10^{-7}
400	3.9×10^{-8}

(a) Ramsdell and Andrews (1986).

Table 4.1-5. Percent frequency of occurrence of mixing-layer thickness by season and time of day.

Mixing layer (m)	Winter Night	Winter Day	Summer Night	Summer Day
<250	65.7	35.0	48.5	1.2
250-500	24.7	39.8	37.1	9.0
>500	9.6	25.2	14.4	89.9

releases. Tables 4.1-8 and 4.1-9, for the 200 East Area, present diffusion factor tables for both elevated and ground-level releases, respectively. An effective stack height of 89 m (292 ft) has been assumed for elevated releases in Table 4.1-8, based on an actual stack height of 60 m (197 ft) and a typical plume rise of 28 m (92 ft).

4.1.7 Air Quality

National Ambient Air Quality Standards have been set by the U.S. Environmental Protection Agency (EPA), as mandated in the 1970 Clean Air Act and the Clean Air Act Amendments of 1990. Ambient air is that portion of the atmosphere, external to buildings, to which the general public has access. The standards define levels of air quality that are necessary, with an adequate margin of safety, to protect the public health (primary standards) and the public welfare (secondary standards). Standards exist for sulfur oxides (measured as sulfur dioxide), nitrogen dioxide, carbon monoxide, total suspended particulates (TSP), fine particulates (PM_{10}), lead, and ozone. The standards specify the maximum pollutant concentrations and frequencies of occurrence that are allowed for specific averaging periods. The averaging periods vary from 1 hour to 1 year, depending on the pollutant.

Table 4.1-6. Percent probabilities for extended periods of surface-based inversions.

Months	Inversion duration 12 hr	24 hr	48 hr
January-February	54.0	2.5	0.28
March-April	50.0	<0.1	<0.1
May-June	10.0	<0.1	<0.1
July-August	18.0	<0.1	<0.1
September-October	64.0	0.11	<0.1
November-December	50.0	1.2	0.13

Table 4.1-7. Annual average atmospheric diffusion factors (X/Q') for the Skagit-Hanford Site for ground-level release based on 1983 to 1987 data.

	X/Q' (s/m^3)									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	5.62×10^{-6}	8.82×10^{-7}	4.03×10^{-7}	2.44×10^{-7}	1.70×10^{-7}	8.19×10^{-8}	3.13×10^{-8}	1.56×10^{-8}	9.94×10^{-9}	7.11×10^{-9}
NNE	5.39×10^{-6}	8.48×10^{-7}	3.88×10^{-7}	2.36×10^{-7}	1.64×10^{-7}	7.95×10^{-8}	3.05×10^{-8}	1.53×10^{-8}	9.74×10^{-9}	6.98×10^{-9}
NE	5.39×10^{-6}	8.49×10^{-7}	3.89×10^{-7}	2.37×10^{-7}	1.64×10^{-7}	7.96×10^{-8}	3.05×10^{-8}	1.53×10^{-8}	9.74×10^{-9}	6.98×10^{-9}
ENE	6.00×10^{-6}	9.46×10^{-7}	4.34×10^{-7}	2.64×10^{-7}	1.84×10^{-7}	8.89×10^{-8}	3.41×10^{-8}	1.71×10^{-8}	1.09×10^{-8}	7.83×10^{-9}
E	7.12×10^{-6}	1.13×10^{-6}	5.19×10^{-7}	3.16×10^{-7}	2.20×10^{-7}	1.07×10^{-7}	4.12×10^{-8}	2.07×10^{-8}	1.32×10^{-8}	9.50×10^{-9}
ESE	1.08×10^{-5}	1.72×10^{-6}	7.90×10^{-7}	4.81×10^{-7}	3.35×10^{-7}	1.63×10^{-7}	6.27×10^{-8}	3.15×10^{-8}	2.01×10^{-8}	1.44×10^{-8}
SE	1.38×10^{-5}	2.19×10^{-6}	1.00×10^{-6}	6.10×10^{-7}	4.24×10^{-7}	2.05×10^{-7}	7.84×10^{-8}	3.92×10^{-8}	2.49×10^{-8}	1.78×10^{-8}
SSE	7.92×10^{-6}	1.25×10^{-6}	5.68×10^{-7}	3.44×10^{-7}	2.39×10^{-7}	1.15×10^{-7}	4.36×10^{-8}	2.17×10^{-8}	1.38×10^{-8}	9.83×10^{-9}
S	7.15×10^{-6}	1.11×10^{-6}	5.02×10^{-7}	3.03×10^{-7}	2.09×10^{-7}	9.94×10^{-8}	3.73×10^{-8}	1.84×10^{-8}	1.16×10^{-8}	8.24×10^{-9}
SSW	2.69×10^{-6}	4.14×10^{-7}	1.86×10^{-7}	1.12×10^{-7}	7.72×10^{-8}	3.67×10^{-8}	1.37×10^{-8}	6.73×10^{-9}	4.24×10^{-9}	3.01×10^{-9}
SW	2.54×10^{-6}	3.92×10^{-7}	1.76×10^{-7}	1.06×10^{-7}	7.28×10^{-8}	3.45×10^{-8}	1.28×10^{-8}	6.30×10^{-9}	3.96×10^{-9}	2.81×10^{-9}
WSW	2.44×10^{-6}	3.75×10^{-7}	1.69×10^{-7}	1.01×10^{-7}	6.98×10^{-8}	3.31×10^{-8}	1.23×10^{-8}	6.06×10^{-9}	3.82×10^{-9}	2.71×10^{-9}
W	2.87×10^{-6}	4.38×10^{-7}	1.97×10^{-7}	1.18×10^{-7}	8.13×10^{-8}	3.86×10^{-8}	1.44×10^{-8}	7.08×10^{-9}	4.47×10^{-9}	3.18×10^{-9}
WNW	4.23×10^{-6}	6.50×10^{-7}	2.94×10^{-7}	1.77×10^{-7}	1.22×10^{-7}	5.85×10^{-8}	2.20×10^{-8}	1.09×10^{-8}	6.91×10^{-9}	4.93×10^{-9}
NW	5.78×10^{-6}	9.00×10^{-7}	4.09×10^{-7}	2.47×10^{-7}	1.71×10^{-7}	8.17×10^{-8}	3.08×10^{-8}	1.53×10^{-8}	9.67×10^{-9}	6.90×10^{-9}
NNW	5.87×10^{-6}	9.20×10^{-7}	4.19×10^{-7}	2.54×10^{-7}	1.76×10^{-7}	8.49×10^{-8}	3.23×10^{-8}	1.61×10^{-8}	1.03×10^{-8}	7.33×10^{-9}

Table 4.1-8. Annual average atmospheric diffusion factors (X/Q') for the 200 East Area for an 89-m release based on 1983 to 1987 data.

	χ/Q' (s/m^3)									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	6.28×10^{-8}	3.81×10^{-8}	3.21×10^{-8}	2.64×10^{-8}	2.20×10^{-8}	1.43×10^{-8}	7.37×10^{-9}	4.36×10^{-9}	3.06×10^{-9}	2.33×10^{-9}
NNE	2.83×10^{-8}	2.25×10^{-8}	1.90×10^{-8}	1.54×10^{-8}	1.27×10^{-8}	7.99×10^{-9}	3.96×10^{-9}	2.29×10^{-9}	1.59×10^{-9}	1.20×10^{-9}
NE	3.43×10^{-8}	2.54×10^{-8}	2.22×10^{-8}	1.82×10^{-8}	1.50×10^{-8}	9.55×10^{-9}	4.73×10^{-9}	2.73×10^{-9}	1.88×10^{-9}	1.42×10^{-9}
ENE	5.02×10^{-8}	3.14×10^{-8}	2.74×10^{-8}	2.27×10^{-8}	1.90×10^{-8}	1.23×10^{-8}	6.27×10^{-9}	3.68×10^{-9}	2.56×10^{-9}	1.95×10^{-9}
E	6.62×10^{-8}	6.81×10^{-8}	6.46×10^{-8}	5.53×10^{-8}	4.71×10^{-8}	3.14×10^{-8}	1.65×10^{-8}	9.83×10^{-9}	6.91×10^{-9}	5.28×10^{-9}
ESE	7.70×10^{-8}	9.62×10^{-8}	8.70×10^{-8}	7.21×10^{-8}	6.01×10^{-8}	3.87×10^{-8}	1.94×10^{-8}	1.13×10^{-8}	7.79×10^{-9}	5.89×10^{-9}
SE	1.06×10^{-7}	8.66×10^{-8}	7.05×10^{-8}	5.57×10^{-8}	4.52×10^{-8}	2.77×10^{-8}	1.32×10^{-8}	7.49×10^{-9}	5.10×10^{-9}	3.82×10^{-9}
SSE	9.92×10^{-8}	6.13×10^{-8}	4.80×10^{-8}	3.72×10^{-8}	2.96×10^{-8}	1.76×10^{-8}	8.16×10^{-9}	4.52×10^{-9}	3.05×10^{-9}	2.27×10^{-9}
S	1.59×10^{-7}	8.24×10^{-8}	6.09×10^{-8}	4.58×10^{-8}	3.58×10^{-8}	2.05×10^{-8}	9.08×10^{-9}	4.89×10^{-9}	3.25×10^{-9}	2.39×10^{-9}
SSW	1.05×10^{-7}	5.38×10^{-8}	3.91×10^{-8}	2.91×10^{-8}	2.26×10^{-8}	1.28×10^{-8}	5.57×10^{-9}	2.95×10^{-9}	1.94×10^{-9}	1.41×10^{-9}
SW	8.68×10^{-8}	5.30×10^{-8}	3.99×10^{-8}	3.00×10^{-8}	2.34×10^{-8}	1.33×10^{-8}	5.84×10^{-9}	3.13×10^{-9}	2.07×10^{-9}	1.52×10^{-9}
WSW	9.78×10^{-8}	5.21×10^{-8}	3.77×10^{-8}	2.79×10^{-8}	2.16×10^{-8}	1.22×10^{-8}	5.29×10^{-9}	2.83×10^{-9}	1.87×10^{-9}	1.37×10^{-9}
W	1.52×10^{-7}	7.83×10^{-8}	5.84×10^{-8}	4.42×10^{-8}	3.48×10^{-8}	2.02×10^{-8}	9.09×10^{-9}	4.96×10^{-9}	3.32×10^{-9}	2.46×10^{-9}
WNW	1.02×10^{-7}	5.49×10^{-8}	4.21×10^{-8}	3.25×10^{-8}	2.59×10^{-8}	1.55×10^{-8}	7.25×10^{-9}	4.06×10^{-9}	2.76×10^{-9}	2.07×10^{-9}
NW	8.34×10^{-8}	5.34×10^{-8}	4.23×10^{-8}	3.32×10^{-8}	2.68×10^{-8}	1.64×10^{-8}	7.89×10^{-9}	4.50×10^{-9}	3.09×10^{-9}	2.33×10^{-9}
NNW	5.23×10^{-8}	3.87×10^{-8}	3.22×10^{-8}	2.59×10^{-8}	2.13×10^{-8}	1.34×10^{-8}	6.72×10^{-9}	3.93×10^{-9}	2.74×10^{-9}	2.08×10^{-9}

Table 4.1-9. Annual average atmospheric diffusion factors (X/Q') for the 200 East Area for a ground-level release based on 1983 to 1987 data.

	X/Q' (s/m^3)									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	3.87×10^{-6}	6.08×10^{-7}	2.79×10^{-7}	1.70×10^{-7}	1.18×10^{-7}	5.72×10^{-8}	2.20×10^{-8}	1.10×10^{-8}	7.05×10^{-9}	5.06×10^{-9}
NNE	2.04×10^{-6}	3.21×10^{-7}	1.47×10^{-7}	8.93×10^{-8}	6.20×10^{-8}	3.00×10^{-8}	1.15×10^{-8}	5.75×10^{-9}	3.67×10^{-9}	2.63×10^{-9}
NE	2.43×10^{-6}	3.83×10^{-7}	1.75×10^{-7}	1.06×10^{-7}	7.39×10^{-8}	3.57×10^{-8}	1.37×10^{-8}	6.84×10^{-9}	4.35×10^{-9}	3.12×10^{-9}
ENE	3.30×10^{-6}	5.18×10^{-7}	2.37×10^{-7}	1.44×10^{-7}	1.00×10^{-7}	4.86×10^{-8}	1.86×10^{-8}	9.33×10^{-9}	5.95×10^{-9}	4.27×10^{-9}
E	8.99×10^{-6}	1.42×10^{-6}	6.54×10^{-7}	3.99×10^{-7}	2.77×10^{-7}	1.35×10^{-7}	5.19×10^{-8}	2.60×10^{-8}	1.66×10^{-8}	1.19×10^{-8}
ESE	9.59×10^{-6}	1.52×10^{-6}	6.94×10^{-7}	4.22×10^{-7}	2.93×10^{-7}	1.41×10^{-7}	5.40×10^{-8}	2.69×10^{-8}	1.71×10^{-8}	1.23×10^{-8}
SE	6.34×10^{-6}	9.93×10^{-7}	4.52×10^{-7}	2.73×10^{-7}	1.89×10^{-7}	9.08×10^{-8}	3.44×10^{-8}	1.71×10^{-8}	1.08×10^{-8}	7.74×10^{-9}
SSE	3.91×10^{-6}	6.07×10^{-7}	2.75×10^{-7}	1.66×10^{-7}	1.15×10^{-7}	5.50×10^{-8}	2.08×10^{-8}	1.03×10^{-8}	6.51×10^{-9}	4.64×10^{-9}
S	4.24×10^{-6}	6.51×10^{-7}	2.93×10^{-7}	1.76×10^{-7}	1.21×10^{-7}	5.75×10^{-8}	2.14×10^{-8}	1.05×10^{-8}	6.63×10^{-9}	4.71×10^{-9}
SSW	2.53×10^{-6}	3.87×10^{-7}	1.73×10^{-7}	1.04×10^{-7}	7.12×10^{-8}	3.36×10^{-8}	1.24×10^{-8}	6.06×10^{-9}	3.80×10^{-9}	2.69×10^{-9}
SW	2.98×10^{-6}	4.61×10^{-7}	2.08×10^{-7}	1.25×10^{-7}	8.57×10^{-8}	4.06×10^{-8}	1.51×10^{-8}	7.37×10^{-9}	4.63×10^{-9}	3.28×10^{-9}
WSW	2.60×10^{-6}	3.99×10^{-7}	1.79×10^{-7}	1.07×10^{-7}	7.39×10^{-8}	3.50×10^{-8}	1.30×10^{-8}	6.37×10^{-9}	4.01×10^{-9}	2.84×10^{-9}
W	4.45×10^{-6}	6.86×10^{-7}	3.10×10^{-7}	1.87×10^{-7}	1.29×10^{-7}	6.15×10^{-8}	2.31×10^{-8}	1.14×10^{-8}	7.22×10^{-9}	5.14×10^{-9}
WNW	3.65×10^{-6}	5.66×10^{-7}	2.57×10^{-7}	1.55×10^{-7}	1.07×10^{-7}	5.15×10^{-8}	1.95×10^{-8}	9.67×10^{-9}	6.14×10^{-9}	4.38×10^{-9}
NW	3.67×10^{-6}	5.72×10^{-7}	2.61×10^{-7}	1.58×10^{-7}	1.09×10^{-7}	5.26×10^{-8}	2.00×10^{-8}	9.97×10^{-9}	6.34×10^{-9}	4.53×10^{-9}
NNW	3.56×10^{-6}	5.60×10^{-7}	2.56×10^{-7}	1.56×10^{-7}	1.08×10^{-7}	5.24×10^{-8}	2.01×10^{-8}	1.00×10^{-8}	6.40×10^{-9}	4.59×10^{-9}

For clean areas, the EPA has established the Prevention of Significant Deterioration (PSD) program to protect existing ambient air quality while at the same time allowing a margin for future growth. The Hanford Site operates under a PSD permit issued by the EPA in 1980. The permit provides specific limits for emissions of oxides of nitrogen from the Plutonium-Uranium Extraction (PUREX) and Uranium Oxide (UO_3) Plants.

State and local governments have the authority to impose standards for ambient air quality that are stricter than the national standards. Washington State has established more stringent standards for sulfur dioxide and TSP. In addition, Washington State has established standards for volatile organic compounds (VOC), arsenic, fluoride, and other pollutants that are not covered by national standards. The state standards for carbon monoxide, nitrogen dioxide, ozone, PM_{10}, and lead are identical to the national standards. At the local level, the Benton-Franklin Counties Clean Air Authority has the authority to establish more stringent air standards but has not done so. Table 4.1-10 summarizes the relevant air quality standards (federal and supplemental state standards).

4.1.7.1 Prevention of Significant Deterioration

Nitrogen oxide emissions from the PUREX and UO_3 Plants are permitted under the PSD program. There were no PSD permit violations during 1993.

4.1.7.2 Major Stationary Emission Sources

Emission inventories for permitted pollution sources in Benton and Franklin counties are routinely compiled by the Benton-Franklin Counties Clean Air Authority. Table 4.1-11 lists the annual emission rates for stationary sources within the Hanford Site boundaries that have been reported to the Washington State Department of Ecology (Ecology) by DOE.

4.1.7.3 Onsite Monitoring

Monitoring of nitrogen oxides was discontinued after 1990 mostly because of the end of operations at the PUREX Plant. Monitoring of TSP was discontinued in early 1988 when the Basalt Waste Isolation Project, for which those measurements were required, was concluded.

Seventeen air samples for polychlorinated biphenyls (PCBs) analysis were collected during 1993. Nine samples of PCBs were above the detection limit, with results ranging from 0.25 to 3.9 ng/m^3. The other eight results were below the detection limit of 50 ng/sample component, which yields air concentrations of $<=0.03$ to 0.1 ng/m^3. The EPA specifies a general detection limit of 1 ng/m^3 (EPA Method TO-4). However, some of the results below the general detection limit (1 ng/m^3) exceeded the required sensitivity, and thus were included as though they were above the detection limit. This is why the range on the nine detectable samples was 0.25 to 3.9 ng/m^3.

Table 4.1-10. National and Washington State ambient air quality standards.[a]

Pollutant	National Primary	National Secondary	Washington State
Total Suspended Particulates			
Annual geometric mean	NS[b]	NS	60 $\mu g/m^3$
24-h average	NS	NS	150 $\mu g/m^3$
PM-10 (fine particulates)			
Annual arithmetic mean	50 $\mu g/m^3$	50 $\mu g/m^3$	50 $\mu g/m^3$
24-h average	150 $\mu g/m^3$	150 $\mu g/m^3$	150 $\mu g/m^3$
Sulfur Dioxide			
Annual average	0.03 ppm	NS	0.02 ppm
24-h average	0.14 ppm	NS	0.10 ppm
3-h average	NS	0.50 ppm	NS
1-h average	NS	NS	0.40 ppm[c]
Carbon Monoxide			
8-h average	9 ppm	9 ppm	9 ppm
1-h average	35 ppm	35 ppm	35 ppm
Ozone			
1-h average	0.12 ppm	0.12 ppm	0.12 ppm
Nitrogen Dioxide			
Annual average	0.05 ppm	0.05 ppm	0.05 ppm
Lead			
Quarterly average	1.5 $\mu g/m^3$	1.5 $\mu g/m^3$	1.5 $\mu g/m^3$

(a) Source: Ecology (1994). Annual standards are never to be exceeded; short-term standards are not to be exceeded more than once per year unless otherwise noted. Abbreviations: ppm = parts per million; $\mu g/m^3$ = micrograms per cubic meter.
(b) NS = no standard.
(c) 0.25 ppm not to be exceeded more than twice in any 7 consecutive days. Not to be exceeded more than 1 day per calendar year.

Table 4.1-11. Emission rates for stationary emission sources within the Hanford Site for 1993.[a]

Source	Operation (h/yr)	TSP (t/yr)	PM_{10} (t/yr)	SO_2 (t/yr)	NO_x (t/yr)	VOC (t/yr)	CO (t/yr)
300 Area Res. Dis. #2 Boiler	4368	5	4	65	13	0	1
300 Area Boiler #3	0	0	0	0	0	0	0
300 Area Boiler #4	0	0	0	0	0	0	0
300 Area Boiler #5	0	0	0	0	0	0	0
300 Area Boiler #6	4368	3	3	48	10	0	1
200 E Boiler	8760	8	2	232	174	1	64
200 W Boiler	8760	2	0	213	160	1	58
200 E, 200 W Fugitive Coal	8760	107	54	0	0	0	0
200 E Fugitive Emissions	8760	1	0	0	0	0	0
Fugitive Coal Pile 300 Area	8760	4	2	0	0	0	0
Temp. Boiler Res. Dis. 300 Area	8760	15	13	215	43	0	4

(a) Source: Communication from Washington State Department of Ecology; 1993 emission rates. t/yr = tons per year; TSP = total suspended particulates; PM_{10} = fine particulates; SO_2 = sulfur dioxide; NO_x = oxides of nitrogen; VOC = volatile organic compounds; CO = carbon monoxide.

However, PCBs were well below the National Institute of Occupational Safety and Health (DHHS 1985) occupational limit of 1000 ng/m^3 (10-hour time-weighted average). No regulatory limits for PCBs in ambient air have been established (Woodruff et al. 1994).

There were fourteen air samples collected for VOC analysis in 1993. These samples were analyzed for benzene, alkylbenzenes, halogenated alkanes, and alkenes. All of the VOC concentrations measured were well within the maximum allowable concentrations of air contaminants (MACAC) as established in 29 CFR 1910, January 1989.

4.1.7.4 Offsite Monitoring

The only offsite monitoring near the Hanford Site in 1993, for PM_{10}, was conducted by Ecology (Ecology 1994). PM_{10} was monitored at one location in Benton County, at Columbia Center in Kennewick (Table 4.1-12). During 1993, the 24-hour PM_{10} standard established by the state of Washington, 150 μg/m^3, was exceeded twice at the Columbia Center monitoring location; the maximum 24-hour concentration at Columbia Center was 1166 μg/m^3 (the suspected cause was windblown dust); the other occurrence >150 μg/m^3 was 155 μg/m^3. The site did not exceed the annual primary standard, 50 μg/m^3, during 1993. The arithmetic mean for 1993 was 32 μg/m^3 at Columbia Center.

Table 4.1-12. Results of PM_{10} monitoring near the Hanford Site in 1993.[a]

Location	Annual Arithmetic Mean ($\mu g/m^3$)	Max. Concentration ($\mu g/m^3$)	No. Occurrences $> 150\ \mu g/m^3$
Kennewick, Columbia Center	32	1,166	2

(a) Source: Ecology (1994).

4.1.7.5 Background Monitoring

During the past 10 years, carbon monoxide, sulfur dioxide, and nitrogen dioxide have been monitored periodically in communities and commercial areas southeast of Hanford. These urban measurements are typically used to estimate the maximum background pollutant concentrations for the Hanford Site because of the lack of specific onsite monitoring.

Particulate concentrations can reach relatively high levels in eastern Washington State because of exceptional natural events (i.e., dust storms, volcanic eruptions, and large brushfires) that occur in the region. Washington State ambient air quality standards have not considered "rural fugitive dust" from exceptional natural events when estimating the maximum background concentrations of particulates in the area east of the Cascade Mountain crest. In the past, EPA has exempted the rural fugitive dust component of background concentrations when considering permit applications and enforcement of air quality standards. However, EPA is now investigating the prospect of designating parts of Benton, Franklin, and Walla Walla counties as a nonattainment area for PM_{10}. Windblown dust has been identified as a particularly large problem in this area. The Department of Ecology has been working with the EPA and the Benton County Clean Air Authority under a Memorandum of Agreement (MOA) to characterize and document the sources of PM_{10} emissions and develop appropriate control techniques in the absence of formally designating the area nonattainment. At this time, the parties are characterizing the sources of PM_{10} emissions and working through other items in the MOA. A final decision on this issue has not yet been determined by EPA, pending the final results of the PM_{10} characterization analysis.

4.1.8 Special Meteorological Considerations in the 100 Areas

The surface wind pattern at the 100-N Area (see Figure 4.0-1 for location of 100 Areas) is greatly affected by the topographic influence of the Columbia River. The wind rose for station 13 (Figure 4.1-3) shows a prevailing wind direction from the west, with additional west-southwest and southwest winds (along the river) at the 10-m (33-ft) level. The 60-m (200-ft) tower at the 100-N Area provides additional data to define the wind at 60 m (200 ft) (see Figure 4.1-3), which is influenced less by surface features than the 10-m (33-ft) instrument, showing a strong west-northwest wind.

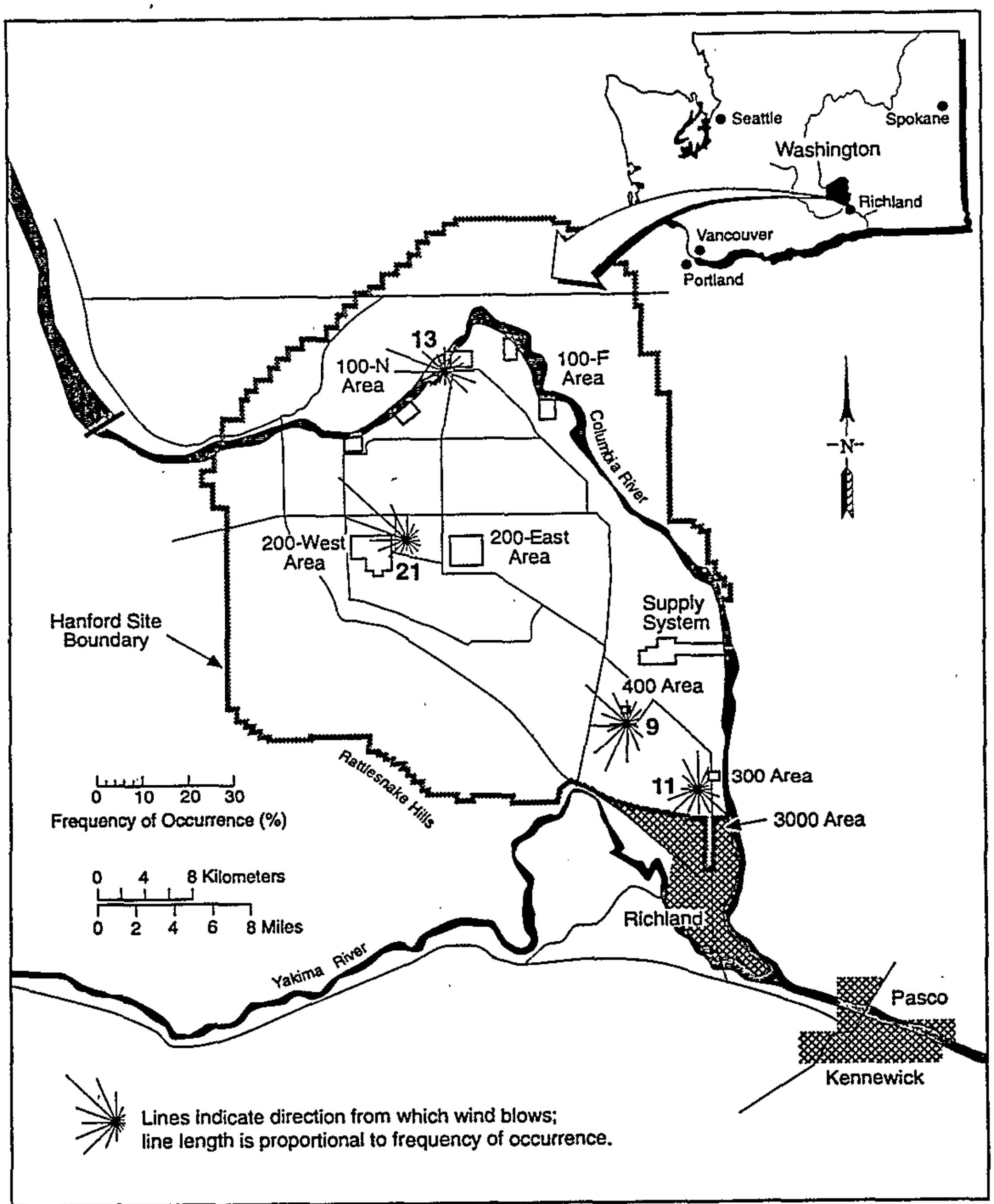

Figure 4.1-3. Wind roses at the 60-m (200-ft) level of the Hanford Meteorological Monitoring Network, 1986 to 1994. The point of each rose represents the direction from which the wind blows.

Temperature measurements for this area were also initiated at the time the 60-m (200-ft) tower was erected. Temperature difference measurements between the 60-m (200-ft) and 10-m (33-ft) levels provide information for determining atmospheric stability, a parameter important to atmospheric dispersion calculations. The X/Q' values in Table 4.1-7 may be used.

4.1.9 Special Meteorological Considerations in the 300 Area

The wind rose for the 300 Area (station 11) at the 10-m (33-ft) level shows that the largest (and approximately the same) percentages of wind blow from the northwest/north-northwest and south-southwest/southwest directions (Figure 4.1-3); however, winds from the southwest quadrant tend to be stronger. The wind pattern at the 60-m (200-ft) level (Figure 4.1-3) is very similar to the pattern at the 10-m (33-ft) level.

Nitrogen dioxide sampling and analysis were performed by the Hanford Environmental Health Foundation (HEHF).

4.2 Geology

Geologic considerations for the Hanford Site include physiography, stratigraphy, structural geology, soil characteristics, and seismicity.

4.2.1 Physiography

The Hanford Site lies within the Columbia Basin and Central Highlands subprovinces of the Columbia Intermontane Province (Figure 4.2-1). The Columbia Intermontane Province is the product of Miocene flood basalt volcanism and regional deformation that occurred over the past 17 million years. The Columbia Plateau is that portion of the Columbia Intermontane Province that is underlain by the Columbia River Basalt Group (Thornbury 1965).

The physiography of the Hanford Site is dominated by the low-relief plains of the Central Plains and anticlinal ridges of the Yakima Folds physiographic regions. The surface topography has been modified within the past several million years by several geomorphic processes: 1) Pleistocene cataclysmic flooding, 2) Holocene eolian activity, and 3) landsliding. Cataclysmic flooding occurred when ice dams in western Montana and northern Idaho were breached, allowing large volumes of water to spill across eastern and central Washington forming the channeled scablands and depositing sediments in the Pasco Basin. The last major flood occurred about 13,000 years ago, during the late Pleistocene Epoch. Anastomosing flood channels, giant current ripples, bergmounds, and giant flood bars are among the landforms created by the floods. The 200 Areas' waste management facilities are located on one prominent flood bar, the Cold Creek bar (Figure 4.2-2) (DOE 1988).

Since the end of the Pleistocene, winds have locally reworked the flood sediments, depositing dune sands in the lower elevations and loess (windblown silt) around the margins of the Pasco Basin. Many sand dunes have been stabilized by anchoring vegetation except where they have been reactivated by disturbing the vegetation.

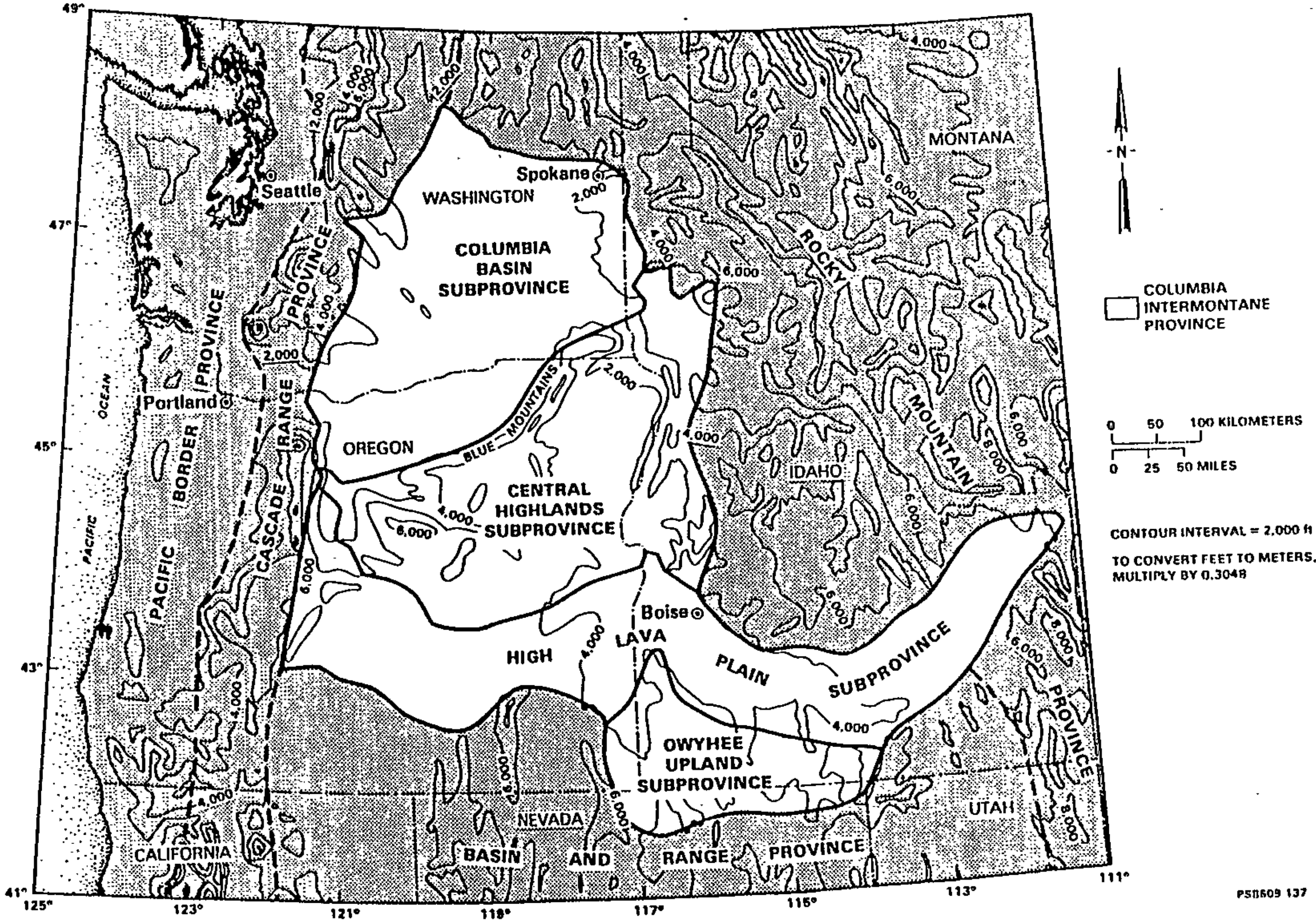

Figure 4.2-1. Physiographic provinces of the Pacific Northwest, with Columbia Intermontane Province shown in white (from DOE 1988).

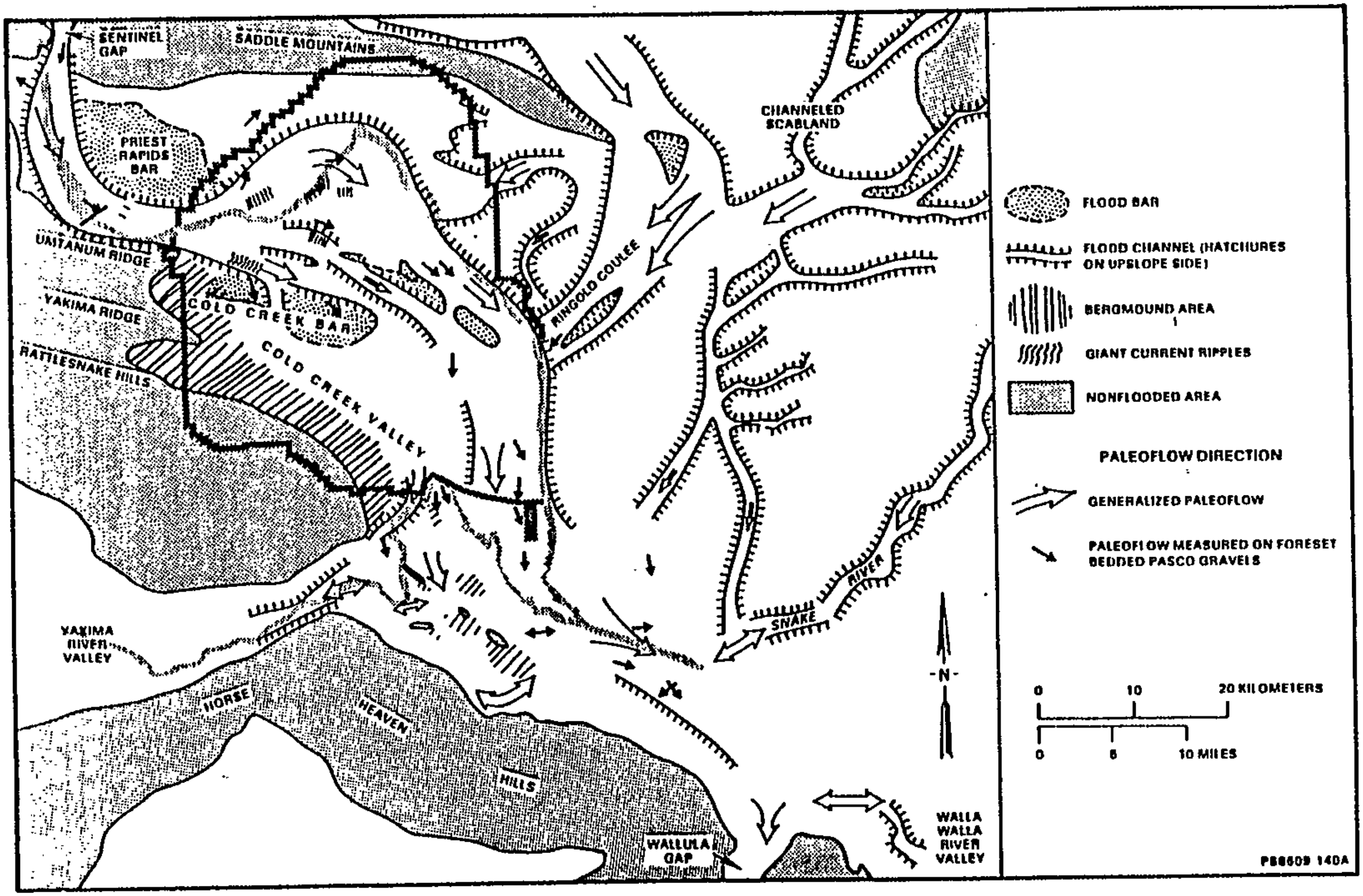

Figure 4.2-2. Paleoflow directions and landforms associated with cataclysmic flooding in the Central Columbia Plateau (after DOE 1988).

Landslides occur along the north limbs of some Yakima Folds and along steep river embankments such as White Bluffs. Landslides on the Yakima Folds occur along contacts between basalt flows or sedimentary units intercalated with the basalt, whereas active landslides at White Bluffs occur in suprabasalt sediments. The active landslides at White Bluffs are principally the result of irrigation activity east of the Columbia River.

4.2.2 Stratigraphy

The stratigraphy of the Hanford Site consists of Miocene-age and younger rocks. Older Cenozoic sedimentary and volcaniclastic rock underlie the Miocene and younger rocks but are not exposed at the surface. The Hanford Site stratigraphy is summarized in Figure 4.2-3 and described in the following subsections. A more detailed discussion of the Hanford Site stratigraphy is given in DOE (1988).

4.2.2.1 Columbia River Basalt Group

The Columbia River Basalt Group (Figure 4.2-3) consists of an assemblage of tholeiitic, continental flood basalts of Miocene age. These flows cover an area of more than 163,170 km^2 (63,000 mi^2) in Washington, Oregon, and Idaho and have an estimated volume of about 174,000 km^3 (67,200 mi^2) (Tolan et al. 1987). Isotopic age determinations suggest flows of the Columbia River Basalt Group were erupted during a period from approximately 17 to 6 million years ago, with more than 98% by volume being erupted in a 2.5 million-year period (17 to 14.5 million years ago).

Columbia River basalt flows were erupted from north-northwest-trending fissures or linear vent systems in north-central and northeastern Oregon, eastern Washington, and western Idaho (Swanson et al. 1979a,b; Waters 1961). The Columbia River Basalt Group is formally divided into five formations, from oldest to youngest: Imnaha Basalt, Picture Gorge Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. Of these, only the Grande Ronde, Wanapum, and Saddle Mountains Basalts are known to be present in the Pasco Basin. The Saddle Mountains Basalt forms the uppermost basalt unit in the Pasco Basin except along some of the bounding ridges where Wanapum and Grande Ronde Basalt flows are exposed.

4.2.2.2 Ellensburg Formation

The Ellensburg Formation (Figure 4.2-3) includes epiclastic and volcaniclastic sedimentary rocks interbedded with the Columbia River Basalt Group in the central and western part of the Columbia Plateau (Schmincke 1964; Smith 1988; Swanson et al. 1979a,b). The age of the Ellensburg Formation is principally Miocene, although locally it may be equivalent to early Pliocene. The thickest accumulations of the Ellensburg Formation lie along the western margin of the Columbia Plateau where Cascade Range volcanic and volcaniclastic materials interfinger with the Columbia River Basalt Group. Within the Pasco Basin, individual interbeds, primarily in the Wanapum and Saddle Mountains Basalts, have been named (i.e., Mabton, Selah, and Cold Creek). The lateral extent and thickness of interbedded sediments generally increase upward in the section (Reidel and Fecht 1981). Two major facies, volcaniclastic and fluvial, are present either as distinct or mixed deposits.

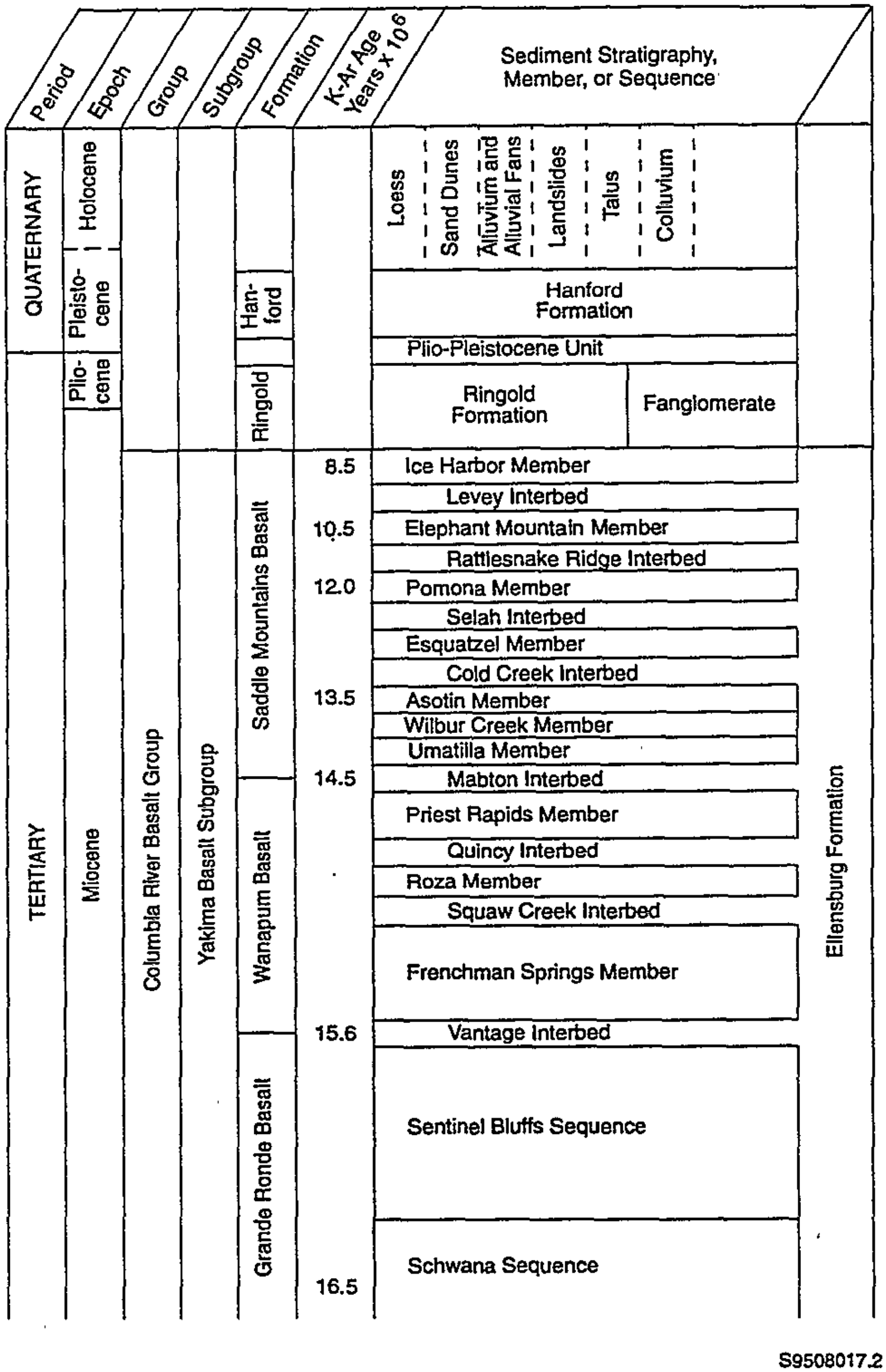

Figure 4.2-3. Stratigraphic column for the Pasco Basin.

4.2.2.3 Suprabasalt Sediments

The suprabasalt sediments within and adjacent to the Hanford Site (Figure 4.2-3) are dominated by the fluvial-lacustrine Ringold Formation and glaciofluvial Hanford formation, with minor eolian and colluvium deposits (Baker et al. 1991; DOE 1988; Tallman et al. 1981).

Ringold Formation. Late Miocene to Pliocene deposits, younger than the Columbia River Basalt Group, are represented by the Ringold Formation within the Pasco Basin (Grolier and Bingham 1978; Gustafson 1973; Newcomb et al. 1972; Rigby and Othberg 1979). The fluvial-lacustrine Ringold Formation was deposited in generally east-west trending valleys by the ancestral Columbia River and its tributaries in response to development of the Yakima Fold Belt. While exposures of the Ringold Formation are limited to White Bluffs within the central Pasco Basin and to Smyrna and Taunton Benches north of the Pasco Basin, extensive data on the Ringold Formation are available from boreholes.

Fluvial deposits of the Ringold Formation can be broken into three facies associations based on proximity to the ancestral Columbia and/or Snake River channels and the related paleography during the time the Ringold Formation was being deposited. Gravel and associated sand and silt represent a migrating channel deposit of the major, thorough going river systems and are generally confined to the central portion of the Pasco Basin. Overbank sand, silt, and clay reflect occasional deposition and flooding beyond the influence of the main river channels, and are generally found along the margins of the Pasco Basin. Fanglomerates, composed of mostly angular basaltic debris derived from side-stream alluvium shed off bedrock ridges, occur locally around the extreme margins of the basin. Over time, the main river channels moved back and forth across the basin, causing a shift in location of the various facies. Periodically, the river channels were blocked, causing lakes to develop in which laminated mud with minor sand was deposited.

In Tallman et al. (1979), the Ringold Formation was divided into four lithofacies units. In ascending order, they are the coarse-grained basal Ringold, the fine-grained lower Ringold, the coarse-grained middle Ringold, and the fine-grained upper Ringold units (Figure 4.2-4). Bjornstad (1984) further subdivided the basal Ringold unit. A new approach is being developed to reevaluate the Ringold stratigraphy using facies associations (Lindsey 1991b; Lindsey and Gaylord 1989). Figure 4.2-4 shows the relationships between these different stratigraphic nomenclatures. The stratigraphic divisions of the Ringold Formation as presented in Lindsey et al. (1992) will be used in this report. Lowermost in the Ringold is Unit A, a fluvial sand and gravel unit that occurs in the central portion of the Pasco Basin, pinching out towards the margins of the basin and onto the anticlines. Unit A correlates to the coarse-grained portion of the Basal Ringold Member. Overlying this coarse-grained unit is the relatively extensive Lower Mud Sequence, consisting of overbank and lacustrine deposits of mud and occasionally sand. The Lower Mud Sequence is found throughout much of the Pasco Basin, pinching out on the southern flank of the Umtanum Ridge-Gable Mountain anticline and near the margins of the basin. It correlates to the fine-grained portion of the Basal Ringold Member and the Lower Ringold Member. Overlying the Lower Mud Sequence is a complex series of sedimentary units deposited by the ancestral Columbia River as it shifted back and forth across the Pasco Basin. Main-channel facies gravel and sand units overlie the Lower Mud Unit over much of the Pasco Basin. Where these coarse-grained units are overlain by an unnamed mud unit, the gravelly sediments are designated Unit B in the eastern part of the basin, or Unit D in the western part. In the 200 West Area and vicinity, there is only one thick sequence of fluvial gravel and sand, part of which may include

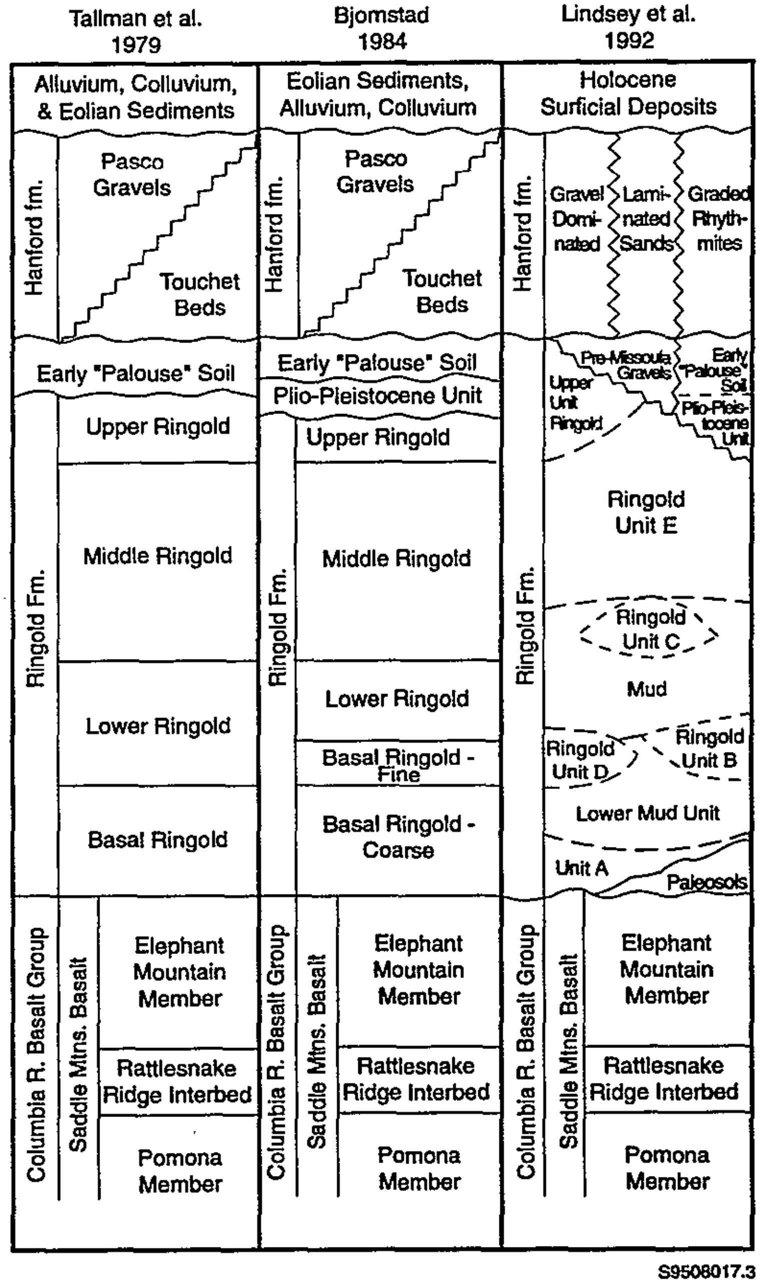

Figure 4.2-4. Stratigraphic column for the Hanford Site showing correlations among various authors.

sediments that correlate to Unit D. In some areas north of Gable Mountain and in the eastern part of the Pasco Basin, the unnamed mud is overlain by another series of coarse-grained fluvial sediments, designated Unit C, and another unnamed mud unit. These unnamed mud units are thickest in the northern and northeastern parts of the Hanford Site, where they form extensive series of overbank/paleosol sequences.

Ringold Unit E correlates to the Middle Ringold Member and may lie directly upon any of the above units. If the underlying unit is a fluvial gravel facies, it is virtually indistinguishable from sediments in Unit E and the entire sequence is generally called Unit E. It is present throughout most of the Hanford Site, with the exception of the northern and northeastern portions, where the Ringold contains virtually no main-channel deposits. Overlying Unit E is the Upper Ringold Unit, which directly corresponds to previous nomenclature and stratigraphy. This unit consists of overbank/ paleosol deposits found over much of the Hanford Site but has been eroded from the 200 East and 300 Areas. Most of White Bluffs on the east side of the Columbia River consists of Upper Ringold sediments.

Deposition of the Ringold Formation was followed by a period of regional incision in the late Pliocene to early Pleistocene. Within the Pasco Basin, this is reflected by the abrupt termination and eroded nature of the top of the Ringold Formation (Bjornstad 1985; Brown 1960; Newcomb et al. 1972). Following incision, a well-developed soil formed on top of the eroded surface. The exact timing and duration of incision are unknown; however, the incision probably occurred between 1 and 3.4 million years ago.

Plio-Pleistocene Unit. A locally derived unit consisting of a sidestream alluvium and/or pedogenic calcrete occurs at the unconformity between the Ringold Formation and the Hanford formation (Bjornstad 1984, 1985). The sidestream alluvial facies is derived from Cold Creek and its tributaries and is characterized by relatively thick zones of unweathered basalt clasts along with pedogenically altered loess or colluvium. The calcrete is relatively thick and impermeable in areas of the western Pasco Basin, often forming an aquitard to downward migration of water in the vadose zone where artificial recharge is occurring.

Early "Palouse" Soil. Overlying the Plio-Pleistocene unit in the Cold Creek syncline area is a fine-grained sand to silt. It is believed to be mainly of eolian origin, derived from either an older reworked Plio-Pleistocene unit or upper Ringold. The early Palouse soil differs from the overlying slackwater flood deposits by a greater calcium-carbonate content, massive structure in core samples, and a high natural gamma response in geophysical logs.

Quaternary Deposits. Aggradation of sediments resumed during the Quaternary following the period of late-Pliocene to early-Pleistocene incision. In the central Columbia Plateau, the Quaternary record is dominated by proglacial cataclysmic flood deposits with lesser amounts of fluvial and eolian deposits lying below, between, and above flood deposits.

Sand and gravel river sediments, referred to informally as the pre-Missoula gravels (PSPL 1982), were deposited after incision of the Ringold and before deposition of the cataclysmic flood deposits. The pre-Missoula gravels are very similar to the Ringold Formation main-channel gravel facies, consisting of dominantly nonbasaltic clasts. These sediments appear to occur in a swath that runs from the Old Hanford Townsite on the eastern side of the Hanford Site across the Site toward Horn Rapids on the Yakima River.

Cataclysmic floods inundated the Pasco Basin a number of times during the Pleistocene, beginning as early as 1 million years ago (Bjornstad and Fecht 1989); the last major flood sequence is dated at about 13,000 years ago by the presence of Mount St. Helens "S" tephra (Mullineaux et al. 1978) interbedded with the flood deposits. The number and timing of cataclysmic floods continues to be debated. Baker et al. (1991) document as many as 10 flood events during the last ice age. The largest and most frequent floods came from glacial Lake Missoula in northwestern Montana; however, smaller floods may have escaped downvalley from glacial Lakes Clark and Columbia along the northern margin of the Columbia Plateau (Waitt 1980), or down the Snake River from glacial Lake Bonneville (Malde 1968). The flood deposits, informally called the Hanford formation, blanket low-lying areas over most of the central Pasco Basin.

Cataclysmic floodwaters entering the Pasco Basin quickly became impounded behind Wallula Gap, which was too restrictive for the volume of water involved. Floodwaters formed temporary lakes with a shoreline up to 381.25 m (1250 ft) in elevation, which lasted only a few weeks or less (Baker 1978). Two end-member types of flood deposits are normally observed: a sand-and-gravel, main-channel facies and a mud-and-sand, slackwater facies. Within the Pasco Basin, these are referred to as the Pasco Gravels and slackwater deposits of the Hanford formation (Myers et al. 1979). Sediments with intermediate grain sizes (e.g., sand-dominated facies) are also present in areas throughout the Pasco Basin, particularly on the south, relatively protected, half of Cold Creek bar.

Clastic dikes are commonly associated with, but not restricted to, cataclysmic flood deposits on the Columbia Plateau. While there is general agreement that clastic dikes formed during cataclysmic flooding, a primary mechanism to satisfactorily explain the formation of all dikes has not been identified (Supply System 1981). Among the more probable explanations are fracturing initiated by hydrostatic loading and hydraulic injection associated with receding floodwaters. These dikes may provide vertical pathways for downward migration of water through the vadose zone.

Alluvium is present, not only as a surficial deposit along major river and stream courses (Figure 4.2-5), but also in the subsurface, where it is found underlying, and interbedded with, proglacial flood deposits. Two types of alluvium are recognized in the Pasco Basin: quartzitic mainstream and basalt-rich sidestream alluvium. Colluvium (talus and slopewash) is a common Holocene deposit in moderate-to-high relief areas. Colluvium, like the dune sand that is found locally in the Pasco Basin, is not commonly preserved in the stratigraphic record. Varying thicknesses of loess or sand mantle much of the Columbia Plateau. Active and stabilized sand dunes are widespread over the Pasco Basin (Figure 4.2-5).

Landslide deposits in the Pasco Basin are of variable age and genesis. Most occur within the basalt outcrops along the ridges, such as on the north side of Rattlesnake Mountain, or steep river embankments such as White Bluffs, where the Upper Ringold Unit crops out in the Pasco Basin (Figure 4.2-5).

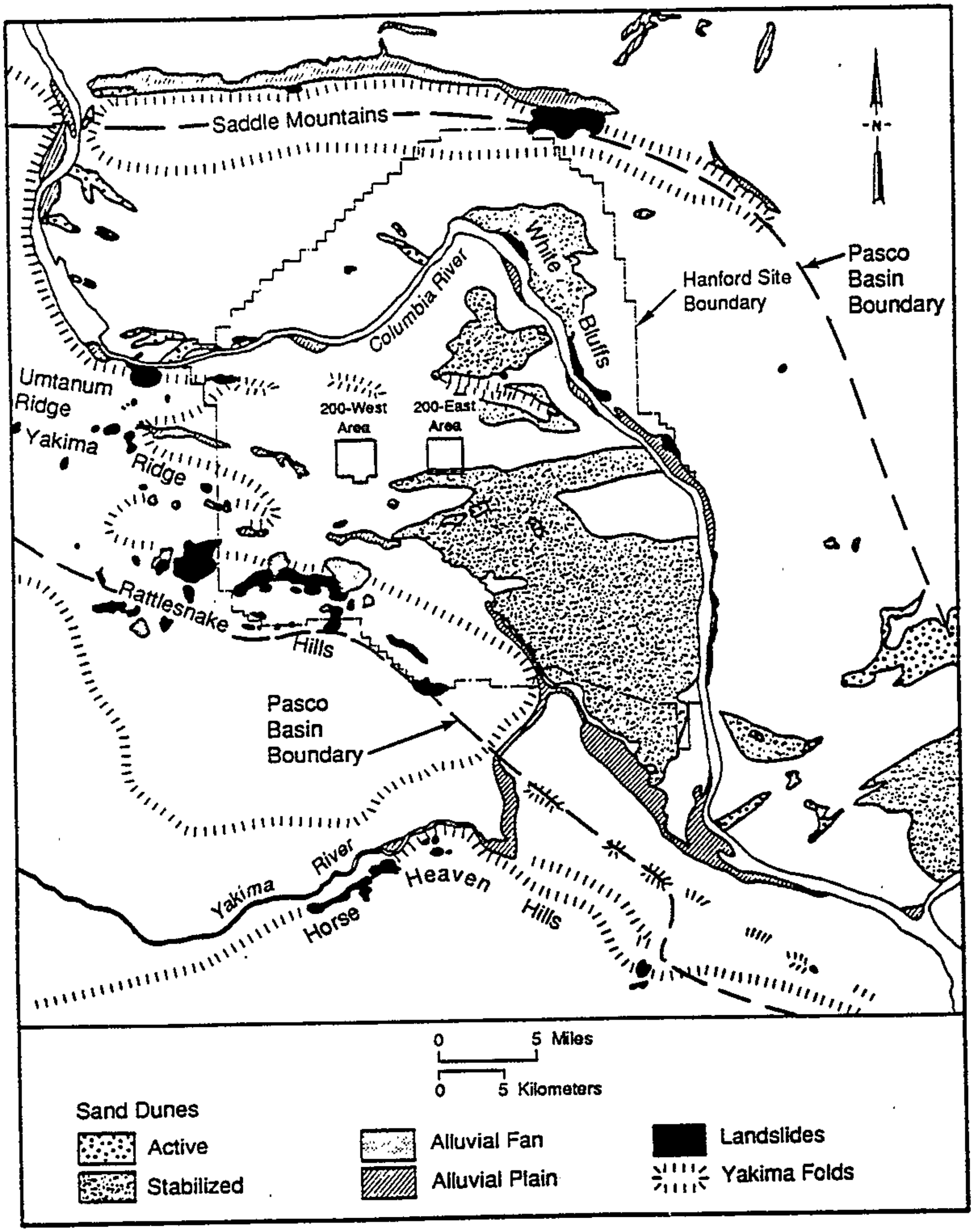

Figure 4.2-5. Location of surficial features (after DOE 1988)

4.2.2.4 100 Areas Stratigraphy

The 100 Areas are spread out along the Columbia River in the northern portion of the Pasco Basin (Figure 4.0-1). All of the 100 Areas, except the 100-B/C Area, lie on the north limb of the Wahluke syncline. The 100-B/C Area lies over the axis of the syncline. The top of basalt in the 100 Areas ranges in elevation from 46 m (150 ft) near the 100-H Area to -64 m (-210 ft) below sea level near the 100-B/C Area. The Ringold and Hanford formations occur throughout this area; the pre-Missoula gravels may be present near the 100-B/C and 100-K Areas but are not readily distinguished from Ringold and Hanford sediments. The Plio-Pleistocene unit and early "Palouse" soil have not been recognized in the 100 Areas.

The Ringold Formation shows a marked west-to-east variation in the 100 Areas (Lindsey 1992). The main channel of the ancestral Columbia River flowed along the front of Umtanum Ridge and through the 100-B/C and 100-K Areas, before turning south to flow along the front of Gable Mountain and/or through the Gable Mountain-Gable Butte gap. This main channel deposited coarse-grained sand and gravel facies of the Ringold Formation (Units A, B, C, and E). Farther to the north and east, however, the Ringold sediments gradually become dominated by the lacustrine and overbank deposits and associated paleosols (Ringold Lower Mud Sequence and unnamed units), with the 100-H Area showing almost none of the gravel facies. In the 100 Areas, the Hanford formation consists primarily of Pasco Gravels facies, with local occurrences of the sand-dominated or slackwater facies. Hydrogeologic reports providing specific information have been written for each of the 100 Areas. These are as follows: 100-B/C Area - Lindberg (1993a); 100-D Area - Lindsey and Jaeger (1993); 100-F Area - Lindsey (1992); 100-H Area - Lindsey and Jaeger (1993); 100-K Area - Lindberg (1993b); and 100-N Area - Hartman and Lindsey (1993).

4.2.2.5 200 Areas Stratigraphy

The geology in the 200 West and 200 East Areas is surprisingly different, although they are separated by a distance of only 6 km (4 mi) (Figure 4.0-1). One of the most complete suprabasalt stratigraphic sections on the Hanford Site, with most of Lindsey's (1991b) Ringold units, as well as the Plio-Pleistocene unit, early "Palouse" soil, and the Hanford formation, is found in the 200 West Area. There are numerous reports on the geology of the 200 West Area, including Connelly et al. (1992b), Lindsey (1991a), and Tallman et al. (1979).

In the 200 East Area, most of the Ringold Formation units are present in the southern part but have been eroded in a complex pattern to the north. On the north side of the 200 East Area, the Hanford formation rests directly on the basalt, and there are no Ringold sediments present. Erosion by the ancestral Columbia River and catastrophic flooding are believed to have removed the Ringold Formation from this area. Neither the Plio-Pleistocene unit nor the early "Palouse" soil have been identified in the 200 East Area. Reports on the geology of the 200 East Area include Connelly et al. (1992a), Lindsey et al. (1992), and Tallman et al. (1979).

4.2.2.6 300 Area Stratigraphy

The 300 Area is located in the southeastern portion of the Hanford Site (Figure 4.0-1). The 300 Area lies above a gentle syncline formed by the intersection of the Palouse Slope and the western side of the Pasco Basin. Over most of the Hanford Site, the uppermost basalt flows belong to the

Elephant Mountain Member, but near the 300 Area, even younger flows belonging to the Ice Harbor Member are found, causing a relative high in the top of basalt surface (Schalla et al. 1988) (the Elephant Mountain and Ice Harbor Members are the top two members of the Saddle Mountains Basalt). Both Ringold and Hanford formation sediments are found in the 300 Area; Swanson (1992) describes the geology in more detail.

4.2.3 Structural Geology of the Region

The Hanford Site is located near the junction of the Yakima Fold Belt and the Palouse structural subprovinces (DOE 1988). These structural subprovinces are defined on the basis of their structural fabric, unlike the physiographic provinces that are defined on the basis of landforms. The Palouse subprovince is primarily a regional paleoslope that dips gently toward the central Columbia Plateau and exhibits only relatively mild structural deformation. The Palouse Slope is underlain by a wedge of Columbia River basalt that thins gradually toward the east and north and laps onto the adjacent highlands.

The principal characteristics of the Yakima Fold Belt are a series of segmented, narrow, asymmetric anticlines that have wavelengths between 5 and 31 km (3 and 19 mi) and amplitudes commonly <1 km (0.6 mi) (Reidel et al. 1989). These anticlinal ridges are separated by broad synclines or basins that, in many cases, contain thick accumulations of Neogene- to Quaternary-age sediments. The deformation of the Yakima Folds occurred under north-south compression. The fold belt was growing during the eruption of the Columbia River Basalt Group and continued to grow into the Pleistocene and probably into the present (Reidel 1984).

Thrust or high-angle reverse faults with fault planes that strike parallel or subparallel to the axial trends are principally found along the limbs of the anticlines (Bentley et al. 1980; Hagood 1985; Reidel 1984; Swanson et al. 1979a,b, 1981). The amount of vertical stratigraphic offset associated with these faults varies but commonly exceeds hundreds of meters.

The Saddle Mountains uplift is a segmented anticlinal ridge extending from near Ellensburg to the western edge of the Palouse Slope. This ridge forms the northern boundary of the Pasco Basin and the Wahluke syncline (Figure 4.2-6). It is generally steepest on the north, with a gently dipping southern limb. A major thrust or high-angle reverse fault occurs on the north side (Reidel 1984).

The Umtanum Ridge-Gable Mountain uplift is a segmented, asymmetrical anticlinal ridge extending 137 km (85 mi) in an east-west direction and passing north of the 200 Areas (Figure 4.2-6), forming the northern boundary of the Cold Creek syncline and the southern boundary of the Wahluke syncline. Three of this structure's segments are located on or adjacent to the Hanford Site. From the west, Umtanum Ridge plunges eastward toward the basin and merges with the Gable Mountain-Gable Butte segment. The latter segment then merges with the Southeast Anticline, which trends southeast before dying out near the Columbia River eastern boundary of the Gable Mountain-Gable Butte segment.

There is a major thrust to high-angle reverse fault on the north side (PSPL 1982) that dies out as it plunges eastward past the Gable Mountain-Gable Butte segment. Gable Mountain and Gable Butte are

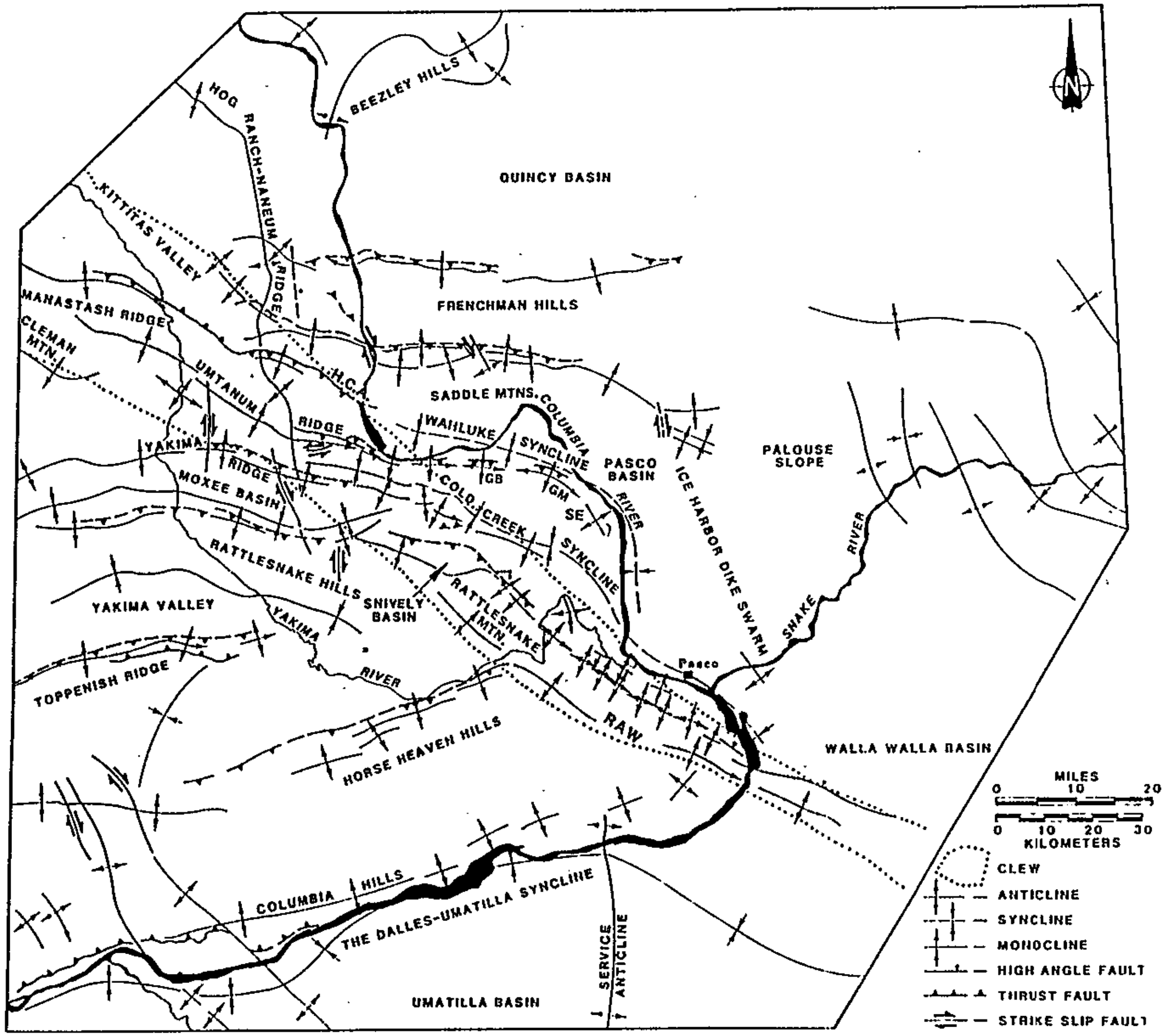

Figure 4.2-6. Location of structural features (Reidel et al. 1989)

two topographically isolated, anticlinal ridges composed of a series of northwest-trending, doubly plunging, echelon anticlines, synclines, and associated faults. The potential for present-day faulting has been identified on Gable Mountain (PSPL 1982).

The Yakima Ridge uplift extends from west of Yakima to the center of the Pasco Basin, where it forms the southern boundary of the Cold Creek syncline (DOE 1988) (Figure 4.2-6). The Yakima Ridge anticline plunges eastward into the Pasco Basin, where it continues on a southeastern trend mostly buried beneath sediments. A thrust to high-angle reverse fault is thought to be present on the north side of the anticline, dying out as the fold extends to the east.

Rattlesnake Mountain is an asymmetrical anticline with a steeply dipping and faulted northern unit that forms the southern boundary of the Pasco Basin (Figure 4.2-6). It extends from the structurally complex Snively Basin area southeast to the Yakima River, where the uplift continues as a series of doubly plunging anticlines (Fecht et al. 1984). At Snively Basin, the Rattlesnake Mountain structure intersects the Rattlesnake Hills anticline, which extends beyond Yakima and has an east-west trend.

The Cold Creek syncline (Figure 4.2-6) lies between the Umtanum Ridge-Gable Mountain uplift and the Yakima Ridge uplift. The Cold Creek syncline is an asymmetric and relatively flat-bottomed structure (DOE 1988). The Wahluke syncline lies between Saddle Mountains and the Umtanum Ridge-Gable Mountain uplifts. It, too, is asymmetric and relatively flat-bottomed, and is broader than the Cold Creek syncline (Myers et al. 1979).

The Cold Creek Fault (previously called the Yakima Barricade geophysical anomaly) (Figure 4.2-6) occurs on the west end of the Cold Creek syncline and coincides with a west-to-east change in hydraulic gradient. The data suggest that this feature is a high-angle fault that has faulted the basalts and, at least, the older Ringold units (Johnson et al. 1993). This fault apparently has not affected younger Ringold units or the Hanford formation.

Another fault, informally called the May Junction fault, is located nearly 4.5 km (3 mi) east of the 200 East Area. Like the Cold Creek fault, this fault is thought to be a high-angle fault that has offset the basalts and the older Ringold units. It does not appear to have affected the younger Ringold units or the Hanford formation.

4.2.4 Soils

Hajek (1966) describes 15 different soil types on the Hanford Site, varying from sand to silty and sandy loam. These are shown in Figure 4.2-7 and briefly described in Table 4.2-1. Various classifications, including land use, are also given in Hajek (1966). The soil classifications given in Hajek (1966) have not been updated to reflect current reinterpretations of soil classifications. Until soils on the Hanford Site are resurveyed, the descriptions presented in Hajek (1966) will continue to be used.

4.2.5 Seismicity

The historic record of earthquakes in the Pacific Northwest dates from about 1840. The early part of this record is based on newspaper reports of structural damage and human perception of the shaking,

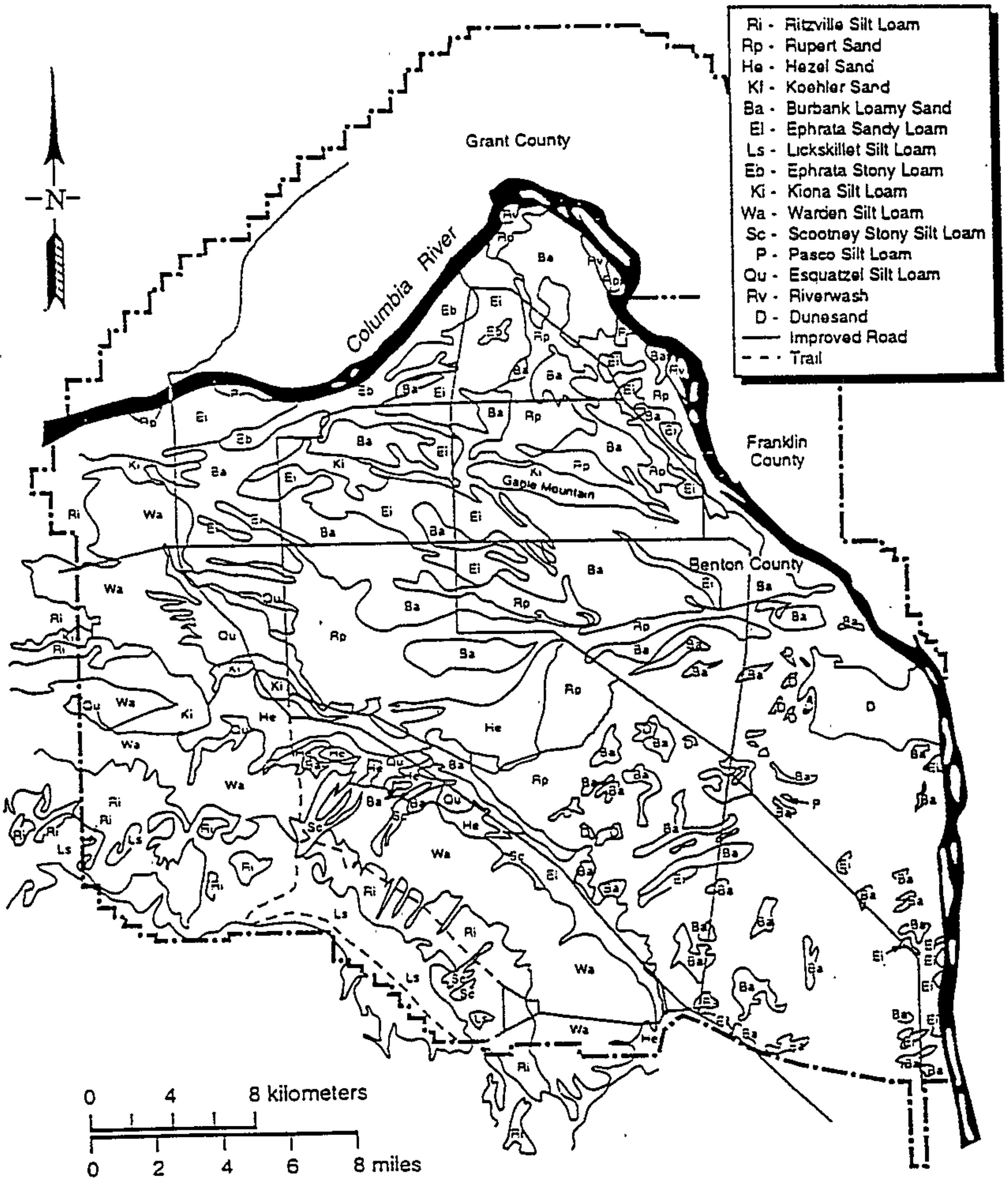

Figure 4.2-7. Soil map of the Hanford Site (from Hajek 1966).

Table 4.2-1. Soil types on the Hanford Site (after Hajek 1966).

Name (symbol)	Description
Ritzville Silt Loam (Ri)	Dark-colored silt loam soils midway up the slopes of the Rattlesnake Hills. Developed under bunch grass from silty wind-laid deposits mixed with small amounts of volcanic ash. Characteristically >150 cm (60 in.) deep, but bedrock may occur at <150 cm (60 in.) but >75 cm (30 in.).
Rupert Sand (Rp)	One of the most extensive soils on the Hanford Site. Brown-to-grayish-brown coarse sand grading to dark grayish-brown at 90 cm (35 in.). Developed under grass, sagebrush, and hopsage in coarse sandy alluvial deposits that were mantled by wind-blown sand. Hummocky terraces and dune-like ridges.
Hezel Sand (He)	Similar to Rupert sands; however, a laminated grayish-brown strongly calcareous silt loam subsoil is usually encountered within 100 cm (39 in.) of the surface. Surface soil is very dark brown and was formed in wind-blown sands that mantled lake-laid sediments.
Koehler Sand (Kf)	Similar to other sandy soils on the Hanford Site. Developed in a wind-blown sand mantle. Differs from other sands in that the sand mantles a lime-silica cemented "Hardpan" layer. Very dark grayish-brown surface layer is somewhat darker than Rupert. Calcareous subsoil is usually dark grayish-brown at about 45 cm (18 in.).
Burbank Loamy Sand (Ba)	Dark-colored, coarse-textured soil underlain by gravel. Surface soil is usually about 40-cm (16-in.) thick but can be 75 cm (30 in.) thick. Gravel content of subsoil ranges from 20% to 80%.
Kiona Silt Loam (Ki)	Occupies steep slopes and ridges. Surface soil is very dark grayish-brown and about 10-cm (4-in.) thick. Dark-brown subsoil contains basalt fragments 30 cm (12 in.) and larger in diameter. Many basalt fragments found in surface layer. Basalt rock outcrops present. A shallow stony soil normally occurring in association with Ritzville and Warden soils.
Warden Silt Loam (Wa)	Dark grayish-brown soil with a surface layer usually 23-cm (9-in.) thick. Silt loam subsoil becomes strongly calcareous at about 50 cm (20 in.) and becomes lighter colored. Granitic boulders are found in many areas. Usually >150 cm (60 in.) deep.

Table 4.2-1. (Cont'd)

Name (symbol)	Description
Ritzville Silt Loam (Ri)	Dark-colored silt loam soils midway up the slopes of the Rattlesnake Hills. Developed under bunch grass from silty wind-laid deposits mixed with small amounts of volcanic ash. Characteristically >150 cm (60 in.) deep, but bedrock may occur at <150 cm (60 in.) but >75 cm (30 in.).
Ephrata Sandy Loam (El)	Surface is dark colored and subsoil is dark grayish-brown medium-textured soil underlain by gravelly material, which may continue for many feet. Level topography.
Ephrata Stony Loam (Eb)	Similar to Ephrata sandy loam. Differs in that many large hummocky ridges are made up of debris released from melting glaciers. Areas between hummocks contain many boulders several feet in diameter.
Scootney Stony Silt Loam (Sc)	Developed along the north slope of Rattlesnake Hills; usually confined to floors of narrow draws or small fanshaped areas where draws open onto plains. Severely eroded with numerous basaltic boulders and fragments exposed. Surface soil is usually dark grayish-brown grading to grayish-brown in the subsoil.
Pasco Silt Loam (P)	Poorly drained very dark grayish-brown soil formed in recent alluvial material. Subsoil is variable, consisting of stratified layers. Only small areas found on the Hanford Site, located in low areas adjacent to the Columbia River.
Esquatzel Silt Loam (Qu)	Deep dark-brown soil formed in recent alluvium derived from loess and lake sediments. Subsoil grades to dark grayish-brown in many areas, but color and texture of the subsoil are variable because of the stratified nature of the alluvial deposits.
Riverwash (Rv)	Wet, periodically flooded areas of sand, gravel, and boulder deposits that make up overflowed islands in the Columbia River and adjacent land.
Dune Sand (D)	Miscellaneous land type that consists of hills or ridges of sand-sized particles drifted and piled up by wind and are either actively shifted or so recently fixed or stabilized that no soil horizons have developed.

Table 4.2-1. (Cont'd)

Name (symbol)	Description
Ritzville Silt Loam (Ri)	Dark-colored silt loam soils midway up the slopes of the Rattlesnake Hills. Developed under bunch grass from silty wind-laid deposits mixed with small amounts of volcanic ash. Characteristically >150 cm (60 in.) deep, but bedrock may occur at <150 cm (60 in.) but >75 cm (30 in.).
Lickskillet Silt Loam (Ls)	Occupies ridge slopes of Rattlesnake Hills and slopes >765 m (2509 ft) elevation. Similar to Kiona series except surface soils are darker. Shallow over basalt bedrock, with numerous basalt fragments throughout the profile.

as classified by the Modified Mercalli Intensity (MMI) scale, and is probably incomplete because the region was sparsely populated. Seismograph networks did not start providing earthquake locations and magnitudes of earthquakes in the Pacific Northwest until about 1960. A comprehensive network of seismic stations that provides accurate locating information for most earthquakes of magnitude >2.5 was installed in eastern Washington in 1969. DOE (1988) provides a summary of the seismicity of the Pacific Northwest, a detailed review of the seismicity in the Columbia Plateau region and the Hanford Site, and a description of the seismic networks used to collect the data.

Large earthquakes (Richter magnitude >7) in the Pacific Northwest have occurred near Puget Sound, Washington, and near the Rocky Mountains in eastern Idaho and western Montana. One of these events occurred near Vancouver Island in 1946, and produced a maximum MMI of VIII and a Richter magnitude of 7.3. Another large event occurred near Olympia, Washington, in 1949 at a maximum intensity of MMI VIII and a Richter magnitude of 7.1. The two largest events near the Rocky Mountains were the 1959 Hebgen Lake earthquake in western Montana, which had a Richter magnitude of 7.5 and a MMI X, and the 1983 Borah Peak earthquake in eastern Idaho, which had a Richter magnitude of 7.3 and a MMI IX.

A large earthquake of uncertain location occurred in north-central Washington in 1872. This event had an estimated maximum MMI ranging from VIII to IX and an estimated magnitude of approximately 7. The distribution of intensities suggests a location within a broad region between Lake Chelan, Washington, and the British Columbia border.

Seismicity of the Columbia Plateau, as determined by the rate of earthquakes per area and the historical magnitude of these events, is relatively low when compared with other regions of the Pacific Northwest, the Puget Sound area, and western Montana/eastern Idaho. Figure 4.2-8 shows the locations of all earthquakes that occurred in the Columbia Plateau before 1969 with a MMI of ≥IV and at magnitude ≥4, and Figure 4.2-9 shows the locations of all earthquakes that occurred from 1969 to 1986 at magnitudes ≥3. The largest known earthquake in the Columbia Plateau occurred in 1936 around Milton-Freewater, Oregon. This earthquake had a magnitude of 5.75 and a maximum MMI of VII, and was followed by a number of aftershocks that indicate a northeast-trending fault plane. Other earthquakes with magnitudes ≥5 and/or intensities of VI occurred along the boundaries of the

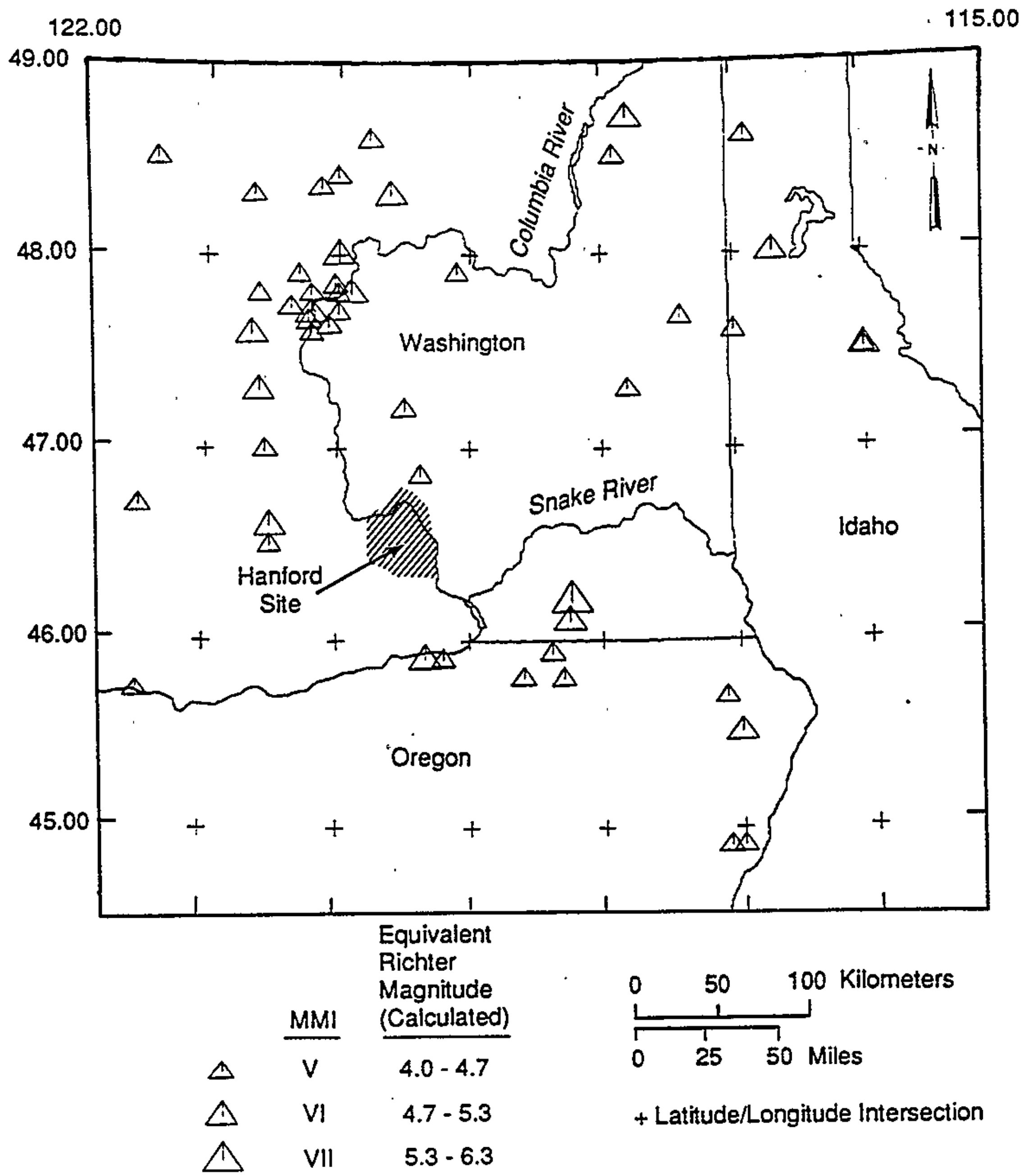

Figure 4.2-8. Historical seismicity of the Columbia Plateau and surrounding areas. All earthquakes between 1850 and March 23, 1969, with a Modified Mercalli Intensity of IV or larger or a magnitude 4 or larger are shown (Rohay 1989).

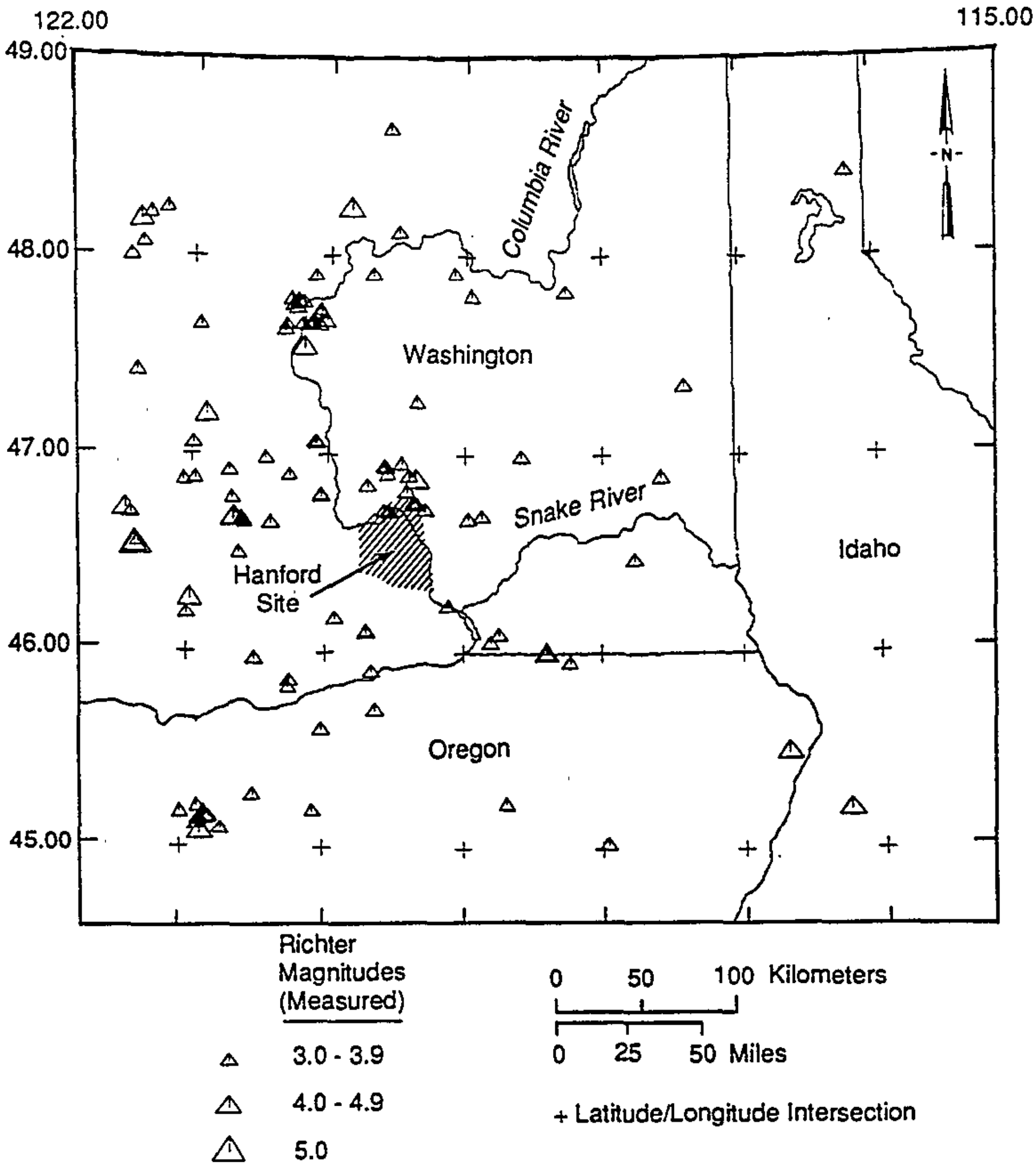

Figure 4.2-9. Seismicity of the Columbia Plateau and surrounding areas as measured by seismographs. All earthquakes between 1969 and 1989 with magnitude 3 or larger are shown (Rohay 1989).

Columbia Plateau in a cluster near Lake Chelan extending into the northern Cascade Range, in northern Idaho and Washington, and along the boundary between the western Columbia Plateau and the Cascade Range. Three MMI VI earthquakes have occurred within the Columbia Plateau, including one event in the Milton-Freewater, Oregon, region in 1921; one near Yakima, Washington, in 1892; and one near Umatilla, Oregon, in 1893.

In the central portion of the Columbia Plateau, the largest earthquakes near the Hanford Site are two earthquakes that occurred in 1918 and 1973. These two events were magnitude 4.4 and intensity V, and were located north of the Hanford Site. Earthquakes often occur in spatial and temporal clusters in the central Columbia Plateau, and are termed "earthquake swarms." The region north and east of the Hanford Site is a region of concentrated earthquake swarm activity, but earthquake swarms have also occurred in several locations within the Hanford Site.

Frequency of earthquakes in a swarm tend to gradually increase and decay with no one outstanding large event within the sequence. Roughly 90% of the earthquakes in swarms have magnitudes of 2 or less. These earthquake swarms generally occur at shallow depths, with 75% of the events located at depths <4 km (2.5 mi). Each earthquake swarm typically lasts several weeks to months, consists of several to a 100 or more earthquakes, and is clustered in an area 5 to 10 km (3 to 6 mi) in lateral dimension. Often, the longest dimension of the swarm area is elongated in an east-west direction. However, detailed locations of swarm earthquakes indicate that the events occur on fault planes of variable orientation, and not on a single, thoroughgoing fault plane.

Earthquakes in the central Columbia Plateau also occur to depths of about 30 km (18 mi). These deeper earthquakes are less clustered and occur more often as single, isolated events. Based on seismic refraction surveys in the region, the shallow earthquake swarms are occurring in the Columbia River Basalts, and the deeper earthquakes are occurring in crustal layers below the basalts.

The spatial pattern of seismicity in the central Columbia Plateau suggests an association of the shallow swarm activity with the east-west-oriented Saddle Mountains anticline. However, this association is complex, and the earthquakes do not delineate a thoroughgoing fault plane that would be consistent with the faulting observed on this structure.

Earthquake focal mechanisms in the central Columbia Plateau generally indicate reverse faulting on east-west planes, consistent with a north-south-directed maximum compressive stress and with the formation of the east-west-oriented anticlinal fold of the Yakima Fold Belt (Rohay 1987). However, earthquake focal mechanisms indicate faulting on a variety of fault plane orientations.

Earthquake focal mechanisms along the western margin of the Columbia Plateau also indicate north-south compression, but here the minimum compressive stress is oriented east-west, resulting in strike-slip faulting (Rohay 1987). Geologic studies indicate an increased component of strike-slip faulting in the western portion of the Yakima Fold Belt. Earthquake focal mechanisms in the Milton-Freewater region to the southeast indicate a different stress field, one with maximum compression directed east-west instead of north-south.

Estimates for the earthquake potential of structures and zones in the central Columbia Plateau have been developed during the licensing of nuclear power plants at the Hanford Site. In reviewing the operating license application for the Washington Public Power Supply System (Supply System) Project

WNP-2, the U.S. Nuclear Regulatory Commission (NRC 1982) concluded that four earthquake sources should be considered for seismic design: the Rattlesnake-Wallula alignment, Gable Mountain, a floating earthquake in the tectonic province, and a swarm area.

For the Rattlesnake-Wallula alignment, which passes along the southwest boundary of the Hanford Site, the NRC estimated a maximum magnitude of 6.5, and for Gable Mountain, an east-west structure that passes through the northern portion of the Hanford Site, a maximum magnitude of 5.0. These estimates were based upon the inferred sense of slip, the fault length, and/or the fault area. The floating earthquake for the tectonic province was developed from the largest event located in the Columbia Plateau, the magnitude 5.75 Milton-Freewater earthquake. The maximum swarm earthquake for the purpose of WNP-2 seismic design was a magnitude 4.0 event, based on the maximum swarm earthquake in 1973. (The NRC concluded that the actual magnitude of this event was smaller than estimated previously.)

The Site design basis earthquake for a safety class 1 System Structure and Component (SSC) is 0.20 g (Hanford Plant Standard, Standard Design Criterion 4.1). The most recent probabilistic seismic hazard analysis calculated an annual probability of recurrence of $5x10^{-4}$ for exceeding the design basis earthquake (Geomatrix 1994).

4.3 Hydrology

Hydrology considerations at the Hanford Site include surface water and groundwater.

4.3.1 Surface Water

Surface water at Hanford includes the Columbia River (northern and eastern sections), riverbank springs along the river, springs on Rattlesnake Mountain, onsite ponds, and offsite water systems directly east of and across the Columbia River from the Hanford Site. In addition, the Yakima River flows along a short section of the southern boundary of the Site (Figure 4.3-1).

4.3.1.1 Columbia River

The Columbia River is the second largest river in the contiguous limited states in terms of total flow and the dominant surface-water body on the Site. The original selection of the Hanford Site for plutonium production and processing was based, in part, on the abundant water provided by the Columbia River. The existence of the Hanford Site has precluded development of this section of river for irrigation and power, and the Hanford Reach is now currently under consideration for designation as a National Wild and Scenic River as a result of congressional action in 1988.

Originating in the mountains of eastern British Columbia, Canada, the Columbia River drains a total area of approximately 70,800 km^2 (27,300 mi^2) en route to the Pacific Ocean. Flow of the Columbia River is regulated by 11 dams within the United States, 7 upstream and 4 downstream of the Site. Priest Rapids is the nearest dam upstream, and McNary is the nearest dam downstream. Lake Wallula, the impoundment created by McNary Dam, extends up near Richland, Washington. Except for the Columbia River estuary, the only unimpounded stretch of the river in the United States is the Hanford Reach, which extends from Priest Rapids Dam to the head of Lake Wallula.

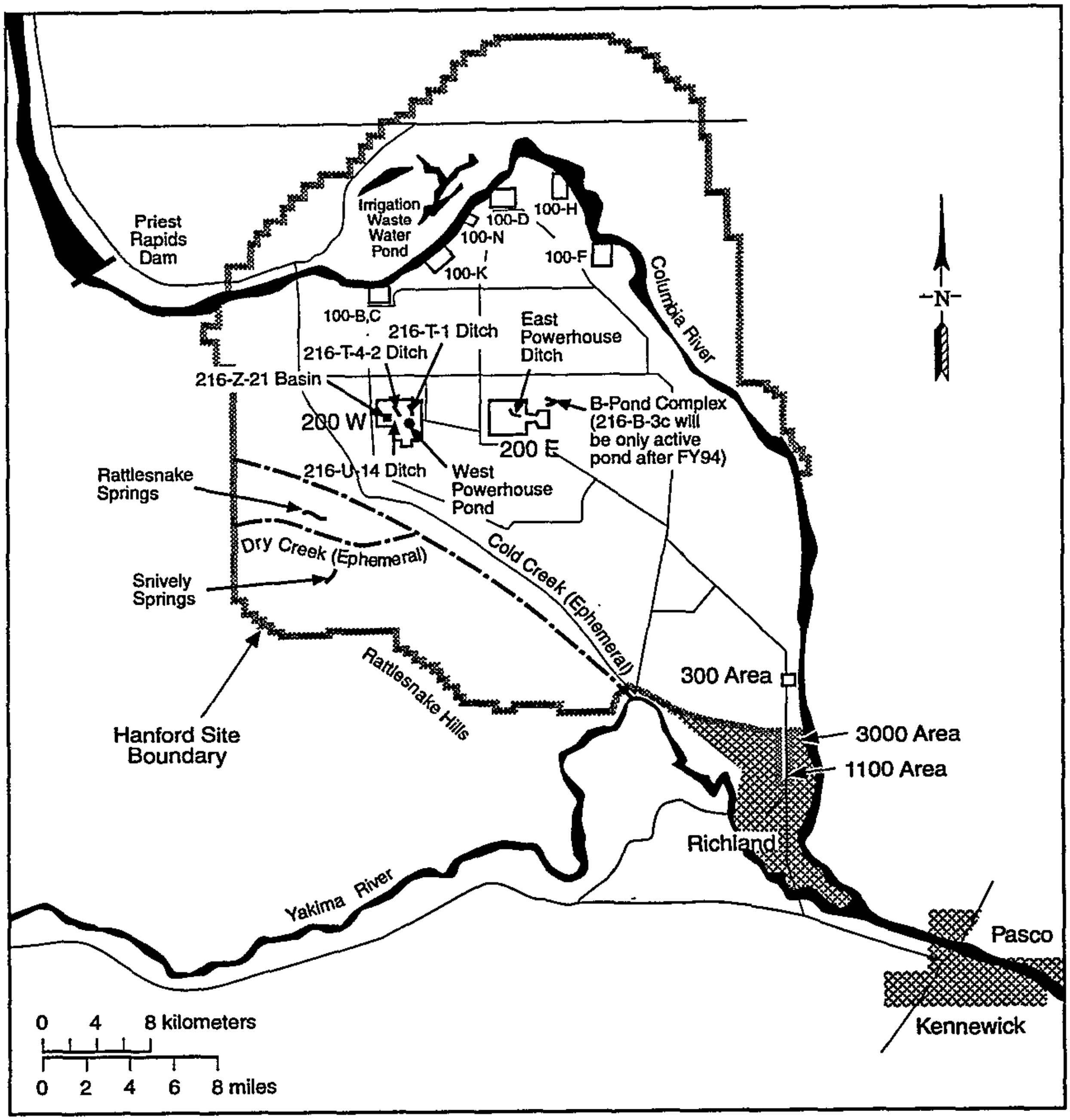

Figure 4.3-1. Temporary ponds and ditches, including ephemeral streams, on the Hanford Site.

Flows through the Reach fluctuate significantly and are controlled primarily by operations at Priest Rapids Dam. Annual flows near Priest Rapids over the last 68 years have averaged nearly 3360 m^3/s (120,000 ft^3/s) (McGavock et al. 1987). Daily average flows range from 1008 to 7000 m^3/s (36,000 to 250,000 ft^3/s). Monthly mean flows typically peak from April through June during spring runoff from winter snows, and are lowest from September through October, accentuated by extensive river-water removal for irrigated agriculture in the Mid-Columbia Basin. As a result of fluctuations in discharges (called hydropeaking), the depth of the river varies significantly over time. Vertical fluctuations of approximately 1.5 m (>5 vertical feet) are not uncommon along the Reach (Dirkes 1993). The width of the river varies from approximately 300 m (984 ft) to 1000 m (3281 ft) within the Hanford Site.

The primary uses of the Columbia River include the production of hydroelectric power and extensive irrigation in the Mid-Columbia Basin. Several communities located on the Columbia River rely on the river as their source of drinking water. Water from the Columbia River along the Hanford Reach is also used as a source of drinking water by several onsite facilities and for industrial uses (Dirkes 1993). In addition, the Columbia River is used extensively for recreation, which includes fishing, hunting, boating, sailboarding, water-skiing, diving, and swimming.

4.3.1.2 Yakima River

The Yakima River, bordering a small length of the southern portion of the Hanford Site, has a low annual flow compared to the Columbia River. The average annual flow, based on nearly 60 years of records, is about 104 m^3/s (3712 ft^3/s), with an average monthly maximum of 490 m^3/s (17,500 ft^3/s) and minimum of 4.6 m^3/s (165 ft^3/s). Approximately one-third of the Hanford Site is drained by the Yakima River System.

4.3.1.3 Springs and Streams

Rattlesnake and Snively springs, located on the western part of the Site, form small surface streams. Rattlesnake Springs flows for about 3 km (1.6 mi) before disappearing into the ground (Figure 4.3-1). Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system along the southern portion of the Hanford Site. These streams drain areas to the west of the Hanford Site and cross the southwestern part of the Site towards the Yakima River. Surface flow, when it occurs, infiltrates rapidly and disappears into the surface sediments in the western part of the Site. The ecological characteristics of these systems are described in Section 4.5.2.2.

4.3.1.4 Runoff

Total estimated precipitation over the Pasco Basin is about 9×10^8 m^3 annually, averaging <20 cm/yr (approximately 8 in./yr). Mean annual runoff from the Pasco Basin is estimated at $<3.1 \times 10^7$ m^3/yr, or approximately 3% of the total precipitation. The basin-wide runoff coefficient is zero for all practical purposes. The remaining precipitation is assumed to be lost through evapotranspiration, with <1% recharging the groundwater system (DOE 1988). However, studies described by Gee et al. (1992) suggest that precipitation may contribute recharge to the groundwater in areas where soils are coarse-textured and bare of vegetation. Studies by Fayer and Walters (1995), Gee and Kirkham (1984), and Gee and Heller (1985) provide information concerning natural recharge rates and evapotranspiration at selected locations on the Hanford Site.

4.3.1.5 Flooding

Large Columbia River floods have occurred in the past (DOE 1987), but the likelihood of recurrence of large-scale flooding has been reduced by the construction of several flood control/water-storage dams upstream of the Site. Major floods on the Columbia River are typically the result of rapid melting of the winter snowpack over a wide area augmented by above-normal precipitation. The maximum historical flood on record occurred June 7, 1894, with a peak discharge at the Hanford Site of 21,000 m^3/s (742,000 ft^3/s). The flood plain associated with the 1894 flood is shown in Figure 4.3-2. The largest recent flood took place in 1948 with an observed peak discharge of 20,000 m^3/s (706,280 ft^3/s) at the Hanford Site. The probability of flooding at the magnitude of the 1894 and 1948 floods has been greatly reduced because of upstream regulation by dams (Figure 4.3-3).

There are no Federal Emergency Management Agency (FEMA) flood plain maps for the Hanford Reach of the Columbia River. FEMA only maps developing areas, and the Hanford Reach is specifically excluded.

There have been fewer than 20 major floods on the Yakima River since 1862 (DOE 1986). The most severe occurred in November 1906, December 1933, and May 1948; discharge magnitudes at Kiona, Washington, were 1870, 1900, and 1050 m^3/s (66,000, 67,000, and 37,000 ft^3/s), respectively. The recurrence intervals for the 1933 and 1948 floods are estimated at 170 and 33 years, respectively. The development of irrigation reservoirs within the Yakima River Basin has considerably reduced the flood potential of the river. The southern border of the Hanford Site could be susceptible to a 100-year flood on the Yakima River (Figure 4.3-4).

Evaluation of flood potential is conducted in part through the concept of the probable maximum flood, which is determined from the upper limit of precipitation falling on a drainage area and other hydrologic factors, such as antecedent moisture conditions, snowmelt, and tributary conditions, that could result in maximum runoff. The probable maximum flood for the Columbia River downstream of Priest Rapids Dam has been calculated to be 40,000 m^3/s (1.4 million ft^3/s) and is greater than the 500-year flood. The flood plain associated with the probable maximum flood is shown in Figure 4.3-5. This flood would inundate parts of the 100 Areas located adjacent to the Columbia River, but the central portion of the Hanford Site would remain unaffected (DOE 1986).

The U.S. Army Corps of Engineers (1989) has derived the Standard Project Flood with both regulated and unregulated peak discharges given for the Columbia River downstream of Priest Rapids Dam. Frequency curves for both natural (unregulated) and regulated peak discharges are also given for the same portion of the Columbia River. The regulated Standard Project Flood for this part of the river is given as 15,200 m^3/s (54,000 ft^3/s) and the 100-year regulated flood as 12,400 m^3/s (440,000 ft^3/s). No maps for the flooded areas are available.

Potential dam failures on the Columbia River have been evaluated. Upstream failures could arise from a number of causes, with the magnitude of the resulting flood depending on the degree of breaching at the dam. The U.S. Army Corps of Engineers evaluated a number of scenarios on the effects of failures of Grand Coulee Dam, assuming flow conditions of 11,000 m^3/s (400,000 ft^3/s). For emergency planning, they hypothesized that 25% and 50% breaches, the "instantaneous" disappearance of 25% or 50% of the center section of the dam, would result from the detonation of nuclear explosives in sabotage or war. The discharge or floodwave resulting from such an instantaneous 50% breach at

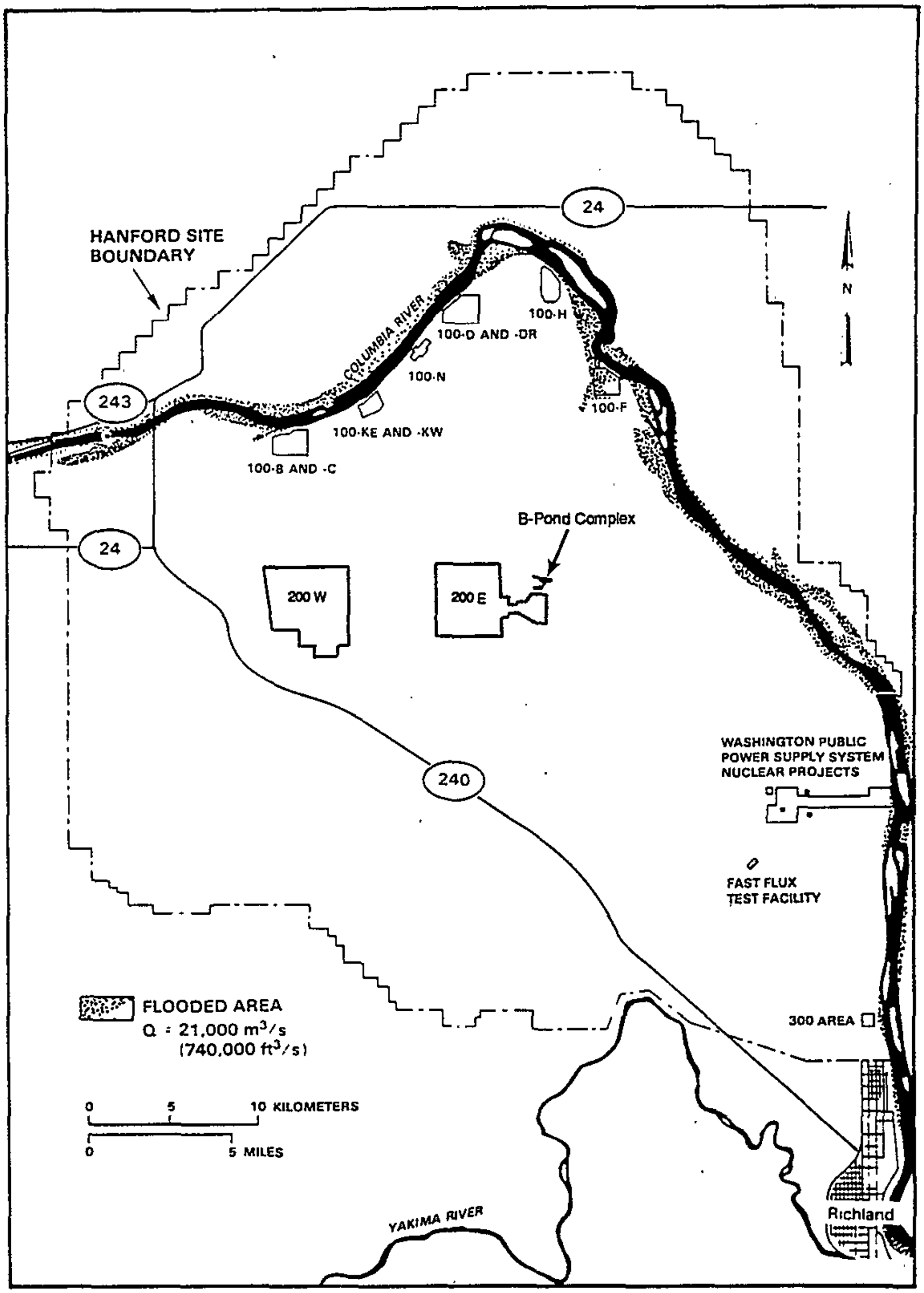

Figure 4.3-2. Flood area during the 1894 flood (DOE 1986).

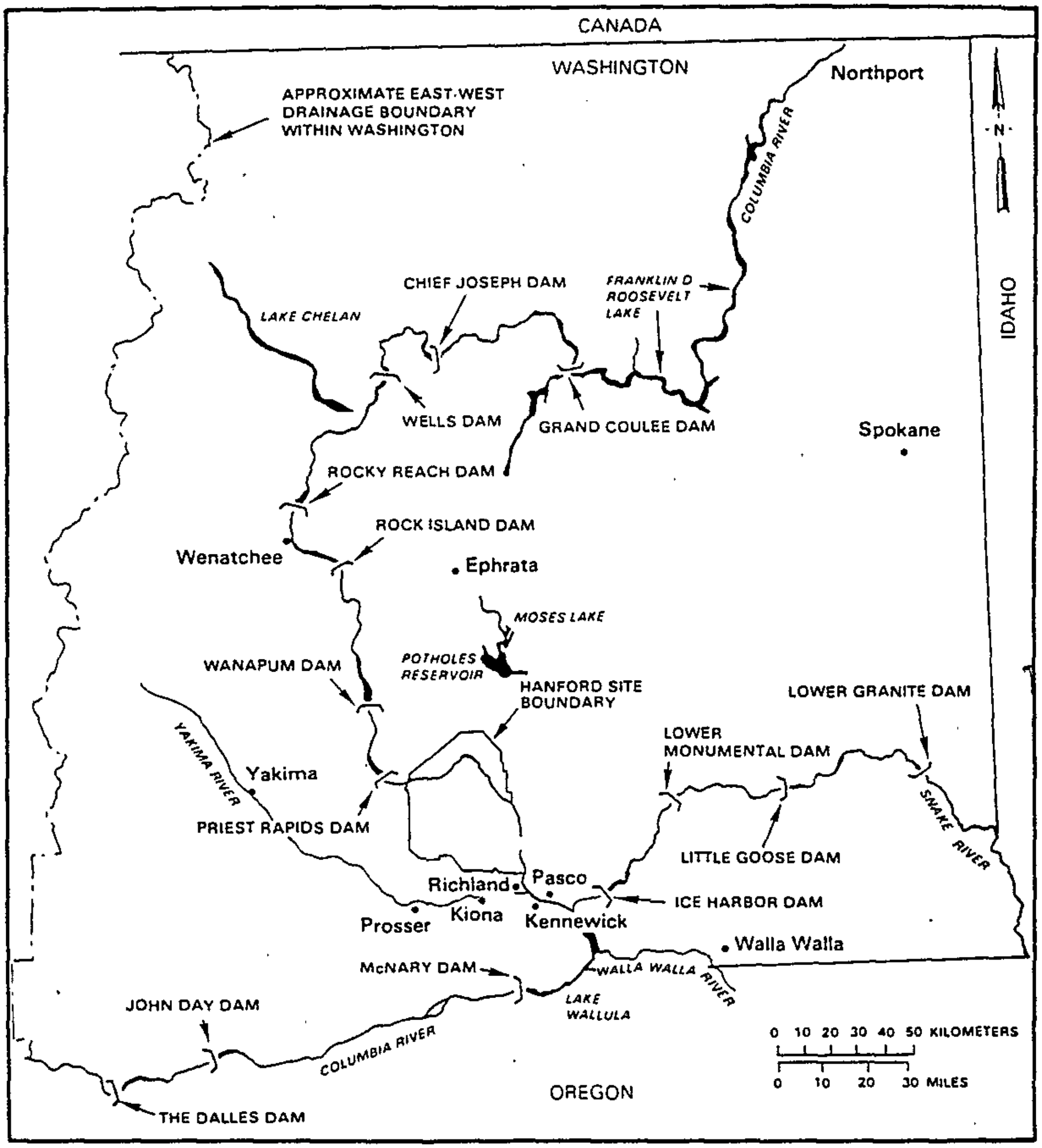

Figure 4.3-3. Locations of principal dams within the Columbia Plateau (after DOE 1988).

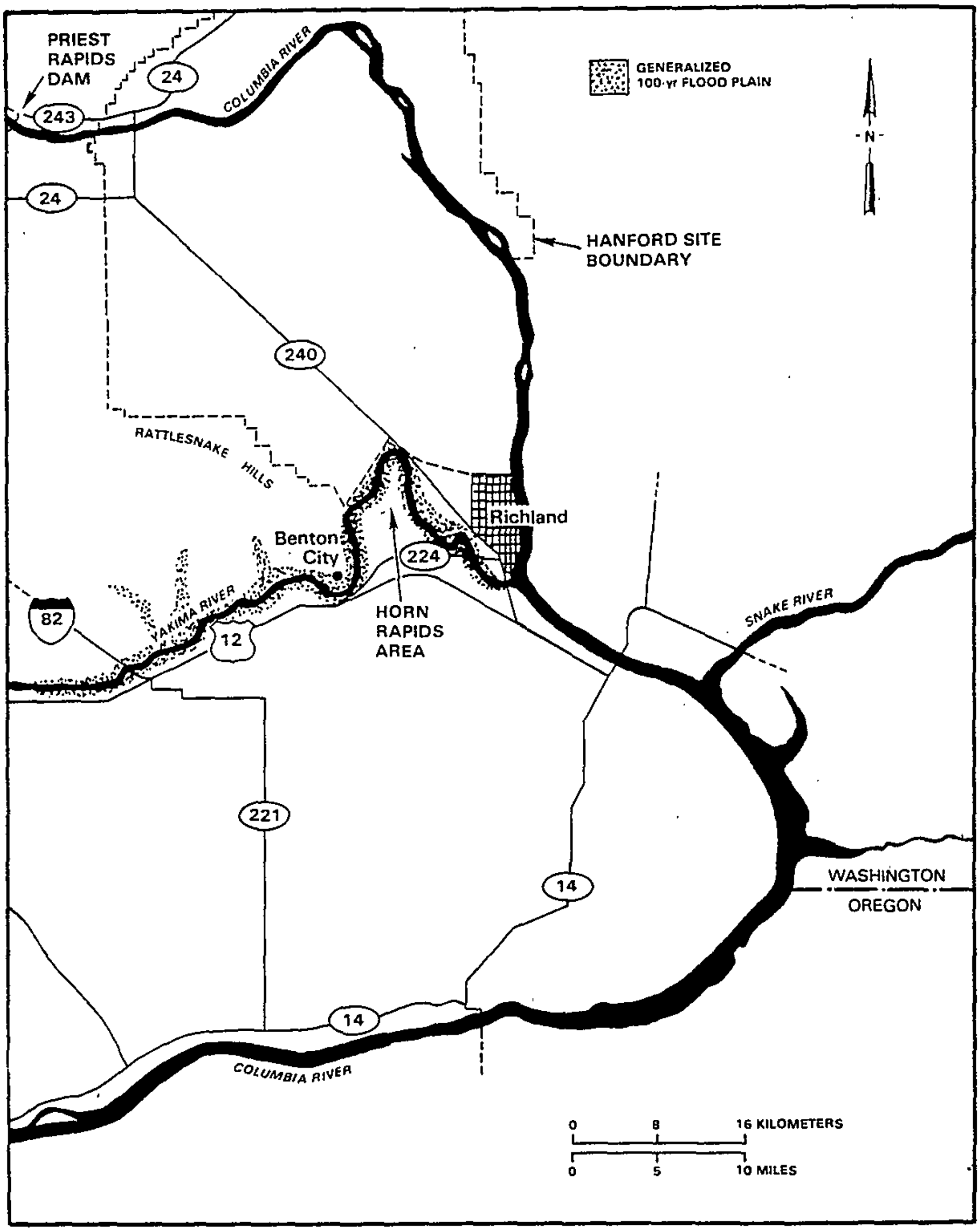

Figure 4.3-4. Flood area from a 100-year flood of the Yakima River near the Hanford Site (DOE 1986).

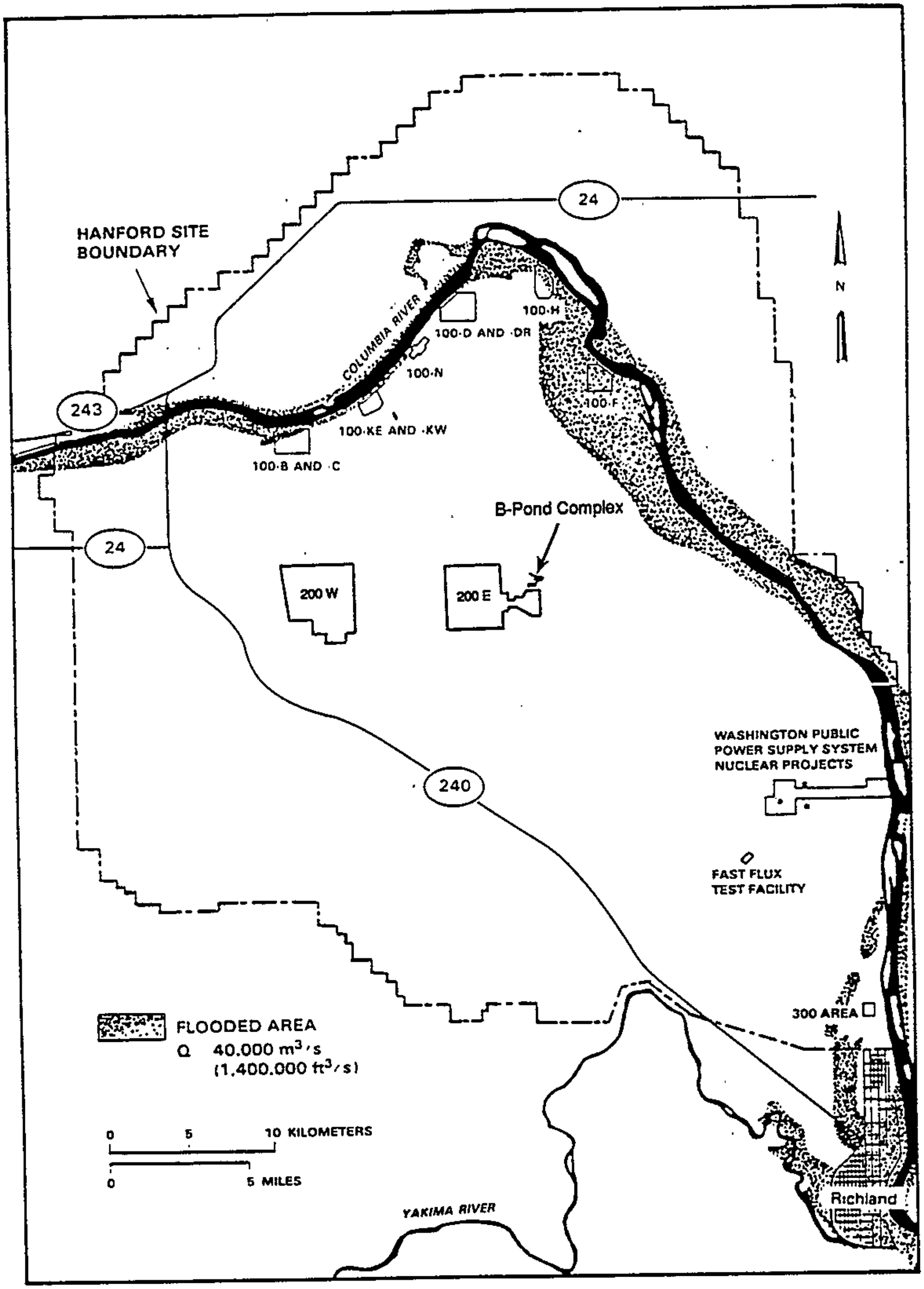

Figure 4.3-5. Flood area for the probable maximum flood (DOE 1986).

the outfall of the Grand Coulee Dam was determined to be 600,000 m^3/s (21 million ft^3/s). In addition to the areas inundated by the probable maximum flood (Figure 4.3-5), the remainder of the 100 Areas, the 300 Area, and nearly all of Richland, Washington, would be flooded (DOE 1986; see also ERDA 1976). No determinations were made for failures of dams upstream, for associated failures downstream of Grand Coulee, or for breaches >50% of Grand Coulee, for two principal reasons:

1. The 50% scenario was believed to represent the largest realistically conceivable flow resulting from either a natural or human-induced breach (DOE 1986), i.e., it was hard to imagine that a structure as large as Grand Coulee Dam would be 100% destroyed instantaneously.

2. It was also assumed that a scenario such as the 50% breach would occur only as the result of direct explosive detonation, and not because of a natural event such as an earthquake, and that even a 50% breach under these conditions would indicate an emergency situation in which there might be other overriding major concerns.

The possibility of a landslide resulting in river blockage and flooding along the Columbia River has also been examined for an area bordering the east side of the river upstream of the city of Richland. The possible landslide area considered was the 75-m- (250-ft-) high bluff generally known as White Bluffs. Calculations were made for an $8x10^5$ m^3 ($1x10^6$ yd^3) landslide volume with a concurrent flood flow of 17,000 m^3/s (600,000 ft^3/s) (a 200-year flood), resulting in a floodwave crest elevation of 122 m (400 ft) above mean sea level. Areas inundated upstream of such a landslide event would be similar to those shown in Figure 4.3-5 (DOE 1986).

A flood risk analysis of Cold Creek was conducted in 1980 as part of the characterization of a basaltic geologic repository for high-level radioactive waste. Such design work is usually done according to the criteria of Standard Project Flood or probable maximum flood, rather than the worst-case or 100-year flood scenario. Therefore, in lieu of 100- and 500-year flood plain studies, a probable maximum flood evaluation was made for a reference repository location directly west of the 200 East Area and encompassing the 200 West Area (Skaggs and Walters 1981). Schematic mapping indicates that access to the reference repository would be unimpaired but that State Route 240 along the southwestern and western areas would not be usable (Figure 4.3-6).

4.3.1.6 Columbia Riverbank Springs

The seepage of groundwater, or springs, into the Columbia River has been known to occur for many years. Riverbank spring discharges were documented along the Hanford Reach long before Hanford operations began during the Second World War (Jenkins 1922). Riverbank springs are monitored for radionuclides at the 100-N Area, the Old Hanford Townsite, and the 300 Area. These relatively small springs flow intermittently, apparently influenced primarily by changes in river level. Hanford-origin contaminants have been documented in these groundwater discharges along the Hanford Reach (Dirkes 1990; DOE 1992a,b; McCormack and Carlile 1984; Peterson and Johnson 1992).

4.3.1.7 Onsite Ponds and Ditches

The ponds and ditches currently active are shown in Figure 4.3-1. In the 200 West Area, the West Powerhouse Pond, the 216-T-1 Ditch, the 216-T-4-2 Ditch, and the 216-Z-21 Basin are active. In the 200 East Area, only the East Powerhouse Ditch and the 216-B-3C Pond are active. The 216-B-3C

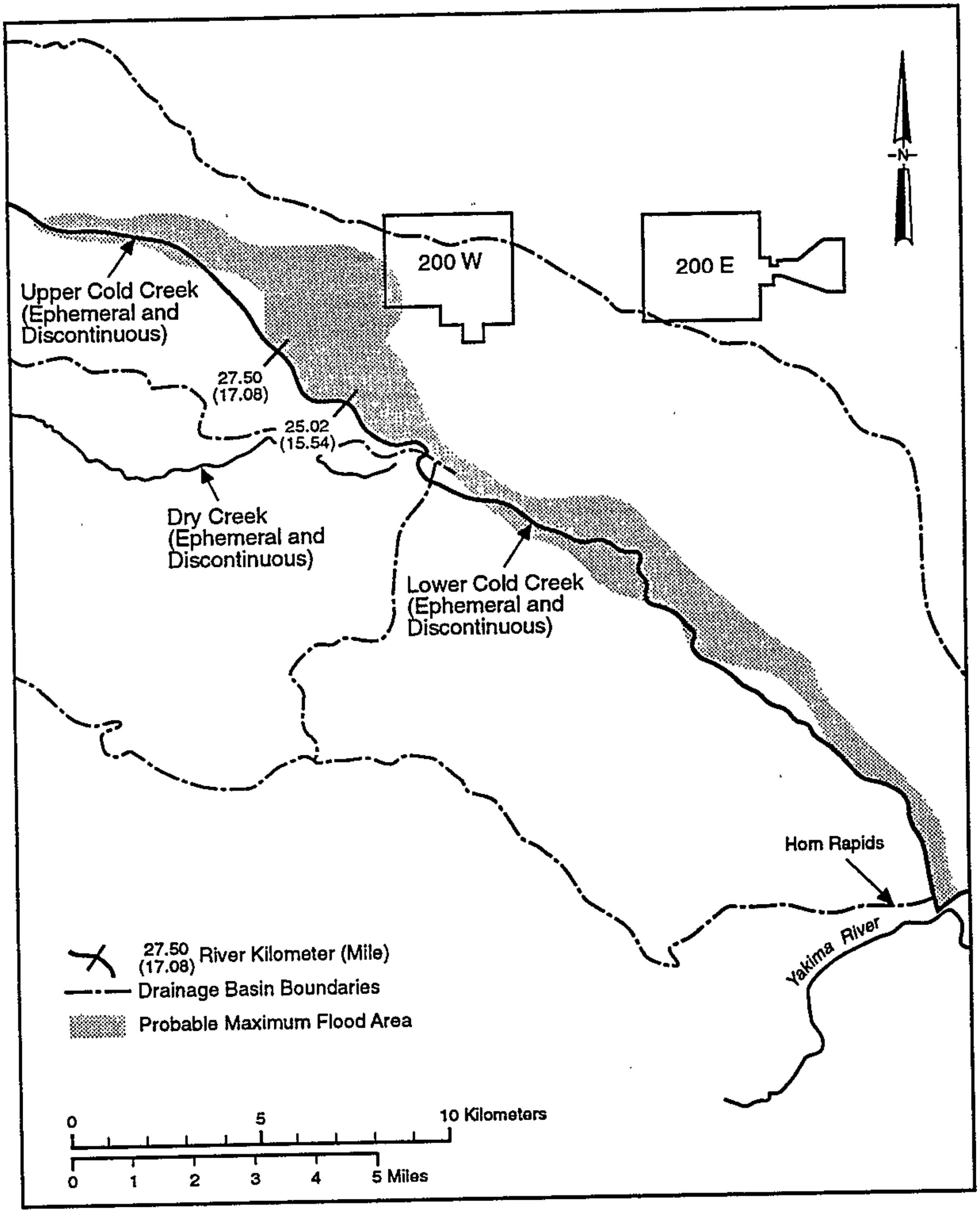

Figure 4.3-6. Extent of probable maximum flood in Cold Creek Area (after Skaggs and Walters 1981).

Pond was originally excavated in the mid-1950s for disposal of process cooling water and other liquid wastes occasionally containing low levels of radionuclides. West Lake is located north of the 200 East Area and is recharged from groundwater (Gephardt et al. 1976). West Lake has not received direct effluent discharges from Site facilities; rather, its existence is caused by the intersection of the elevated water table with the land surface in the topographically low area south of Gable Mountain (and north of the 200 East Area). The artificially elevated water table occurs under much of the Hanford Site and reflects the artificial recharge from Hanford Site operations (see Section 4.3.2). The FFTF Pond is located near the 400 Area and was excavated in 1978 for the disposal of cooling and sanitary water from various facilities in the 400 Area (Woodruff et al. 1993).

The ponds are not accessible to the public and did not constitute a direct offsite environmental impact during 1993 (Dirkes et al. 1994). However, the ponds are accessible to migratory waterfowl, creating a potential pathway for the dispersion of contaminants. Periodic sampling provides an independent check on effluent control and monitoring systems (Woodruff et al. 1993).

4.3.1.8 Offsite Water

Other than rivers and springs, there are no naturally occurring bodies of surface water adjacent to the Hanford Site. However, there are artificial wetlands, caused by irrigation, on the east and west sides of the Wahluke Slope portion of the Hanford Site, which lies north of the Columbia River. Hatcheries and canals associated with the Columbia Basin Irrigation Project constitute the only other artificial surface water expressions in the area. The Ringold Hatchery is the only local hatchery, just south of the Hanford Site boundary on the east side of the Columbia River (just north of the 300 Area). The Riverview Irrigation Canal and four other sites were sampled in 1994 for possible "downwind" airborne contamination. Radionuclide concentrations were found at the same levels detected in the Columbia River both upstream and downstream of the Hanford Site (Dirkes and Hanf 1995).

4.3.2 Groundwater

Groundwater is but one of the many interconnected stages of the hydrologic cycle. Essentially all groundwater, including Hanford's, originates as surface water either from natural recharge such as rain, streams, and lakes, or from artificial recharge such as reservoirs, excess irrigation, canal seepage, deliberate augmentation, industrial processing, and wastewater disposal.

4.3.2.1 Hanford Site Aquifer System

The unconfined aquifer is also referred to as the upper or suprabasalt aquifer system because portions of the upper aquifer system are locally confined or semiconfined, and because in the 200 East Area the unconfined system is in communication with the confined system. However, because the entire suprabasalt aquifer system is interconnected on a Sitewide scale, it is called the Hanford unconfined aquifer for this report. Aquifers located within the Columbia River Basalts are referred to as the confined aquifer system. The following presentation of the Hanford Site aquifer systems is taken from Thorne and Chamness (1992).

Confined Aquifer System. Confined aquifers within the Columbia River Basalts are within relatively permeable sedimentary interbeds and the more porous tops and bottoms of basalt flows. The horizontal hydraulic conductivities of most of these aquifers fall in the range of 10^{-10} to 10^{-4} m/s. Saturated but relatively impermeable dense interior sections of the basalt flows have horizontal hydraulic conductivities ranging from 10^{-15} to 10^{-9} m/s, about five orders of magnitude lower than those of the confined aquifers (DOE 1988). Hydraulic-head information indicates that groundwater in the confined aquifers flows generally towards the Columbia River and, in some places, towards areas of enhanced vertical low communication with the unconfined system (Bauer et al. 1985; DOE 1988; Spane 1987). The confined aquifer system is important for two reasons. First, the system is known to be in hydraulic communication with the unconfined aquifer in the area northeast of the 200 East Area (Graham et al. 1984); second, there is a potential for significant groundwater leakage between the two systems. No data quantifying the leakage between the upper confined and unconfined aquifers are available. Head relationships presented in previous reports (DOE 1988) demonstrate the potential for such leakage. Water chemistry data indicating that interaquifer leakage has taken place in areas of increased vertical communication also have been presented in published reports (Graham et al. 1984; Jensen 1987; Johnson et al. 1993).

Unconfined Aquifer. Groundwater in the unconfined aquifer at Hanford generally flows from recharge areas in the elevated region near the western boundary of the Hanford Site towards the Columbia River on the eastern and northern boundaries (Figure 4.3-7). The Columbia River is the primary discharge area for the unconfined aquifer. The Yakima River borders the Hanford Site on the southwest and is generally regarded as a source of recharge. Along the river shorelines, daily river level fluctuations may result in an elevation change of 1.8 to 2.4 m (6 to 8 ft), and seasonal fluctuations may range from 2.4 to 3 m (8 to 10 ft). As the river stage rises, a pressure wave is transmitted inland through the groundwater. The longer the duration of the higher river stages, the farther inland the effect is propagated. The pressure wave is observed farther inland than the water actually goes. For the river water to flow inland, the river level must be higher than the groundwater surface and must remain high long enough for the water to flow through the sediments. Typically, this inland flow of river water is restricted to within several hundred feet of the shoreline (McMahon and Peterson 1992).

Natural areal recharge from precipitation across the entire Hanford Site is thought to range from about 0 to 10 cm/yr (0 to 4 in./yr) but is probably <2.5 cm/yr (1 in./yr) over most of the Site (Gee and Heller 1985; Bauer and Vaccaro 1990). Since 1944, the artificial recharge from Hanford wastewater disposal has been significantly greater than the natural recharge. An estimated 1.68×10^{12} L (4.44×10^{11} gal) of liquid was discharged to disposal ponds, trenches, and cribs from 1944 to the present.

Horizontal hydraulic conductivities of sand and gravel facies within the Ringold Formation generally range from about 10^{-5} to 10^{-4} m/s (10 to 102 ft/d), compared to 10^{-2} to 10^{-3} m/s (1,000 to 10,000 ft/d) for the Hanford formation (DOE 1988). Because the Ringold sediments are more consolidated and partially cemented, they are about 10 to 100 times less permeable than the sediments of the overlying Hanford formation. Before wastewater disposal operations at the Hanford Site, the uppermost aquifer was mainly within the Ringold Formation and the water table extended into the Hanford formation at only a few locations (Newcomb et al. 1972). However, wastewater discharges have raised the water table elevation across the Site and created groundwater mounds under the two main wastewater disposal areas in the 200 Areas. Because of the general increase in groundwater

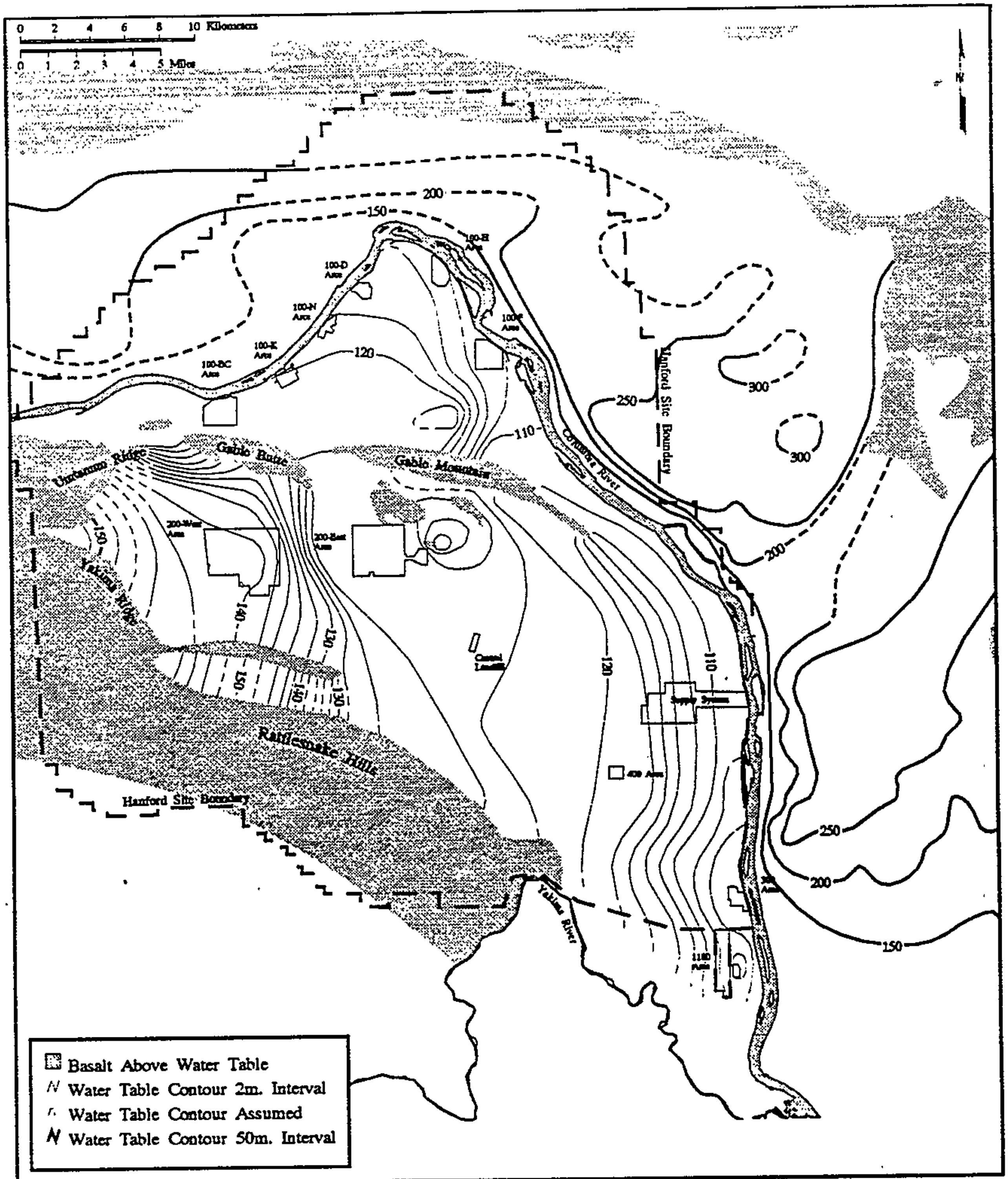

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Figure 4.3-7. Water-table elevations for the unconfined aquifer at Hanford, June 1994 (from Dirkes and Hanf 1995).

elevation, the unconfined aquifer now extends upward into the Hanford formation. This change has resulted in an increase in groundwater transmissivity not only because of the greater volume of groundwater but also because the newly saturated Hanford sediments are highly permeable.

Since the beginning of Hanford operations in 1943, the water table has risen about 27 m (89 ft) under at least one disposal area in the 200 West Area and about 9 m (30 ft) under disposal ponds near the 200 East Area. The volume of water that has been discharged to the ground at the 200 West Area is actually less than that discharged at the 200 East Area. However, the lower conductivity of the aquifer near the 200 West Area has inhibited groundwater movement in this area and resulted in a higher groundwater mound.

The presence of the groundwater mounds has locally affected the direction of groundwater movement, causing radial flow from the discharge areas. Zimmerman et al. (1986) documented changes in water table elevation between 1950 and 1980. They showed that the edge of the mounds migrated outward from the sources over time until about 1980. Water levels have declined in the some areas since 1984 because of decreased wastewater discharges (Kasza et al. 1994).

Limitations of Hydrogeologic Information. The sedimentary architecture of the unconfined aquifer is very complex because of repeated deposition and erosion. Although hundreds of wells have been drilled on the Hanford Site, many penetrate only a small percentage of the total unconfined aquifer thickness, and there is a limited number of useful wells for defining the deeper facies. A number of relatively deep wells were drilled in the early 1980s as part of a study for a proposed nuclear power plant (PSPL 1982), and these data are helpful in defining facies architecture. For most of the thinner and less extensive sedimentary units, correlation between wells is either not possible or uncertain. Coarse-grained units of the Ringold Formation (e.g., Units A, B, C, D, and E) are more permeable than are the fine-grained units, which generally act as aquitards throughout their extent to form semiconfined aquifers. Because these fine-grained units do not extend across the entire Hanford Site, however, the water can move from unconfined to semiconfined conditions and back to unconfined.

A limited amount of hydraulic property data is available from testing of wells. Hydraulic test results from wells on the Hanford Site have been compiled for the Ground-Water Surveillance Project and for environmental restoration efforts (Connelly et al. 1992a,b; Kipp and Mudd 1973; Thorne and Newcomer 1992; Thorne et al. 1993). Depths of the tested intervals have been correlated with the top of the unconfined aquifer as defined by the water-table elevations presented in Newcomer et al. (1991). Most hydraulic tests were done within the upper 15 m (49 ft) of the aquifer, and many were open to more than one geologic unit. In some cases, changes in water table elevation may have significantly changed the unconfined aquifer transmissivity at a well since the time of the hydraulic test. Only three hydraulic tests within the Hanford Site have resulted in estimates of aquifer- specific yield.

Natural Groundwater Quality. Groundwater chemistry in the confined aquifer units displays a range, depending upon depth and residence time, from a calcium and magnesium carbonate water to a sodium and chloride carbonate water. Some of the shallower confined aquifers in the region (e.g., the Wanapum basalt aquifer at <300 m [984 ft]) have exceptionally good water-quality characteristics: <300 mg/L dissolved solids; <0.1 mg/L iron and magnesium; <20 mg/L sodium, sulfate, and chloride; and <10 ppb heavy metals (Johnson et al. 1992). DOE (1992b) discusses the water quality of the background (i.e., unaffected by Hanford discharges) unconfined aquifer on the Hanford Site.

Groundwater Residence Times. Tritium and carbon-14 measurements indicate that residence or recharge time (length of time required to replace the groundwater) takes tens to hundreds of years for spring waters, from hundreds to thousands of years for the unconfined aquifer, and more than 10,000 years for groundwater in the shallow confined aquifer (Johnson et al. 1992). Chlorine-36 and noble gas isotope data suggest ages greater than 100,000 years for groundwater in the deeper confined systems (Johnson et al. 1992). These relatively long residence times are consistent with semiarid-site recharge conditions and point to the need for conservation. For example, in the western Pasco Basin, extensive agricultural groundwater use of the Priest Rapids Member confined aquifer (recharge time >10,000 years) has lowered the potentiometric surface >10 m (33 ft) over several square miles to the west of the Hanford Site. Continued excessive withdrawals along the western edge of the Pasco Basin could eventually impact the confined aquifer flow directions beneath the 200 West Area of the Hanford Site (Johnson et al. 1992).

Hydrology East and North of the Columbia River. The Hanford Site boundary extends to the east and north of the Columbia River to provide a buffer zone for non-Hanford activities such as recreation and agriculture. Hanford Site activities in these areas have not impacted the groundwater. However, the groundwater is impacted by high artificial recharge from irrigation practices and leaky canals. The outlying areas east and north of the Columbia River are irrigated by the South Columbia Basin Irrigation District, which is part of the Columbia Basin Irrigation District, and artificial recharge has elevated the water table throughout the Pasco Basin, in some places by as much as 92 m (300 ft) (Drost et al. 1989).

There are two general hydrologic areas that impinge upon the Hanford Site boundaries to the east and north of the river. The eastern area extends from north to south between the lower slope of the Saddle Mountains and the Esquatzel Diversion canal and includes the Ringold Coulee, White Bluffs area, and Esquatzel Coulee. The water table occurs in the Pasco Gravels in both the Ringold and Esquatzel Coulee, and Brown (1979) reported that runoff from spring discharge at the mouth of Ringold Coulee is >37,850 L/min (10,000 gal/min). Elsewhere, the unconfined aquifer is in the less-transmissive Ringold Formation. Irrigation has also resulted in a series of springs issuing from perched water along the White Bluffs and subsequent slumping and landslides. Irrigation on the Wahluke Slope and the area east of the Columbia River has created perched water tables in addition to very steep hydraulic gradients (Brown 1979; Newcomer et al. 1992).

The other principal area of irrigation is the northern part of the Pasco Basin on the Wahluke Slope between the Columbia River and the Saddle Mountain anticline. Irrigation on Wahluke Slope north of the Columbia River has created ponds and seeps in the Saddle Mountain Wildlife Refuge. The major unconfined groundwater flow is downward movement from the anticlinal axes of the basalt ridges towards the Columbia River where it flows within a syncline. Bauer et al. (1985) reported that lateral water table gradients are essentially equal to or slightly less than the structural gradients on the flanks of the anticlinal fold mountains where the basalt dips steeply.

4.3.3 Water Quality of the Columbia River

The state of Washington has classified the stretch of the Columbia River from Grand Coulee to the Washington-Oregon border, which includes the Hanford Reach, as Class A, Excellent (Ecology 1992).

Class A waters are to be suitable for essentially all uses, including raw drinking water, recreation, and wildlife habitat. State and federal drinking water standards (DWS) apply to the Columbia River and are currently being met.

Water samples were collected quarterly from the Columbia River along cross sections established at the Vernita Bridge (upstream of the Hanford Site) and the Richland Pumphouse (downstream of the Hanford Site), and annually from 100-N, 100-F, Old Hanford Townsite, and the 300 Area during 1994 (Figure 4.3-8) (Dirkes and Hanf 1995). The current major source of heat to the Columbia River in the Hanford Reach is solar radiation (Dauble et al. 1987). The average pH values ranged from 8.0 to 8.4 for all samples from the Vernita Bridge and Richland Pumphouse single-point sampling locations. Mean conductivity values for the same sampling locations range from 128 to 165 μs/cm. There is no apparent difference between the two locations.

Radionuclides consistently detected in the river during 1994 were ^{3}H, ^{90}Sr, ^{129}I, $^{239,240}Pu$, ^{234}U, and ^{238}U. Total alpha and beta measurements (useful indicators of the general radiological quality of the river that provide an early indication of changes in radioactive contamination levels because results are obtained quickly) were similar to the previous year, and were approximately 5% or less of the applicable DWS of 15 and 50 pCi/L, respectively. Tritium measurements continue to be well below state and federal DWS (Dirkes and Hanf 1995). The presence of a ^{3}H concentration gradient at the Richland Pumphouse supports previous conclusions made by Backman (1962) and Dirkes (1993) that contaminants in the 200 Area groundwater plume entering the river at and upstream of the 300 Area are not completely mixed by the time the river reaches the Richland Pumphouse.

All nonradiological water quality standards were met for Class A-designated water (Dirkes and Hanf 1995).

4.3.4 100 Areas Hydrology

Along the Hanford Reach, the water table ranges in depth from 10 to 30 m (33 to 107 ft), and the groundwater flow direction is towards the river. However, during river stages when the river level is above the groundwater table, the flow is away from the river. The water table in the 100 Areas is generally within the Hanford formation, although there are two large areas (Figure 4.3-9) where the water table is within the Ringold Formation (Lindsey 1992). A number of studies on the hydrology of various sites in the 100 Areas discuss the specific hydrologic information available. These reports include 100-B/C Area - Lindberg (1993a); 100-D Area - Lindsey and Jaeger (1993); 100-F Area - Lindsey (1992), Petersen (1992); 100-H Area - Liikala et al. (1988), Lindsey and Jaeger (1993); 100-K Area - Lindberg (1993b); and 100-N Area - Gilmore et al. (1992), Hartman and Lindsey (1993).

4.3.5 200 Areas Hydrology

The hydrology of the 200 Areas is strongly influenced by the discharge of large quantities of wastewater to the ground over a 50-year period. Those discharges have caused elevated water levels across much of the Hanford Site, and specific mounds beneath U Pond in the 200 West Area and B Pond in the 200 East Area. Discharges of water to the ground are being greatly reduced, and corresponding decreases in the water table of up to 9 m (29.5 ft) have been measured in the 200 Areas

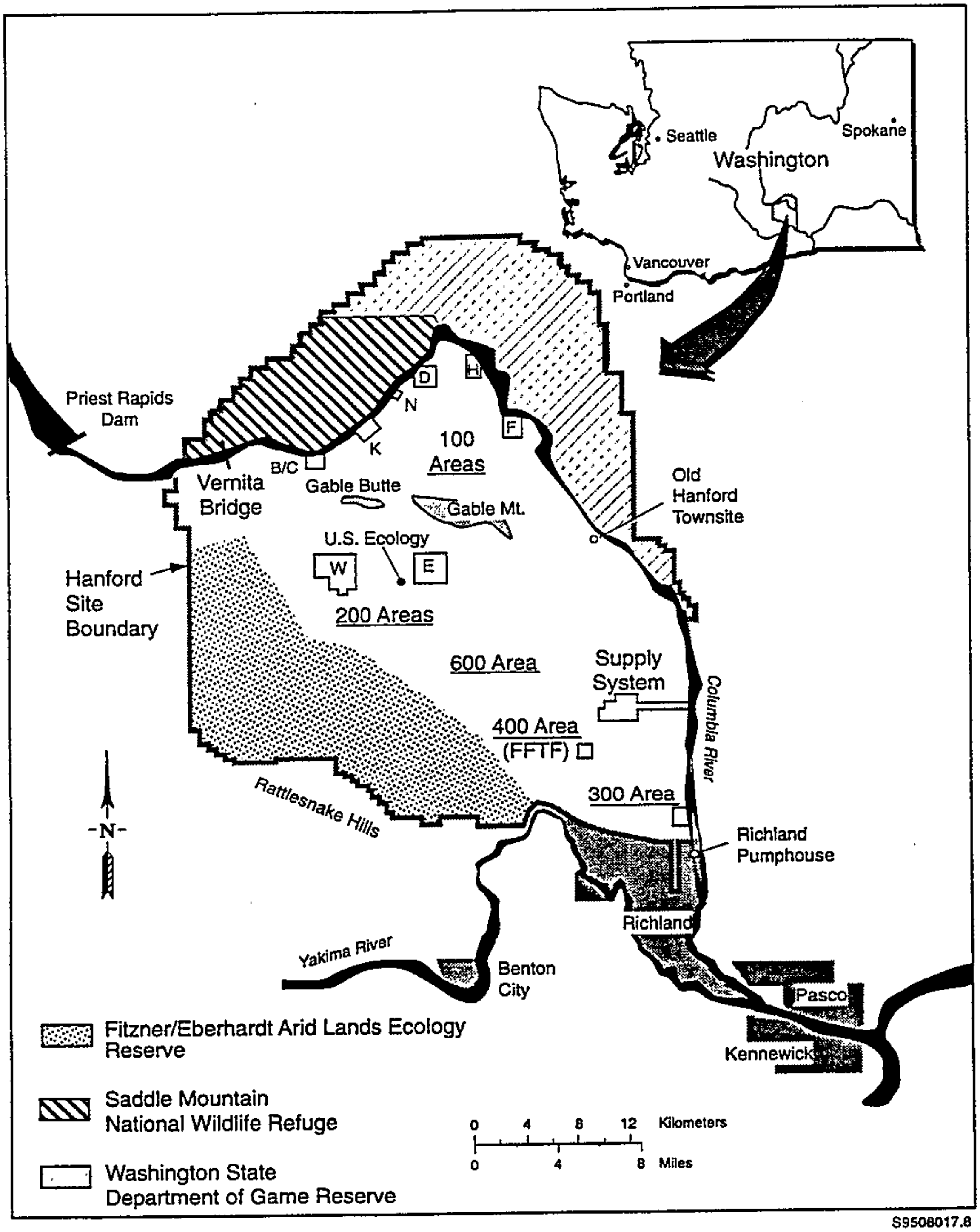

Figure 4.3-8. Sites of Columbia River monitoring (from Dirkes et al. 1994)

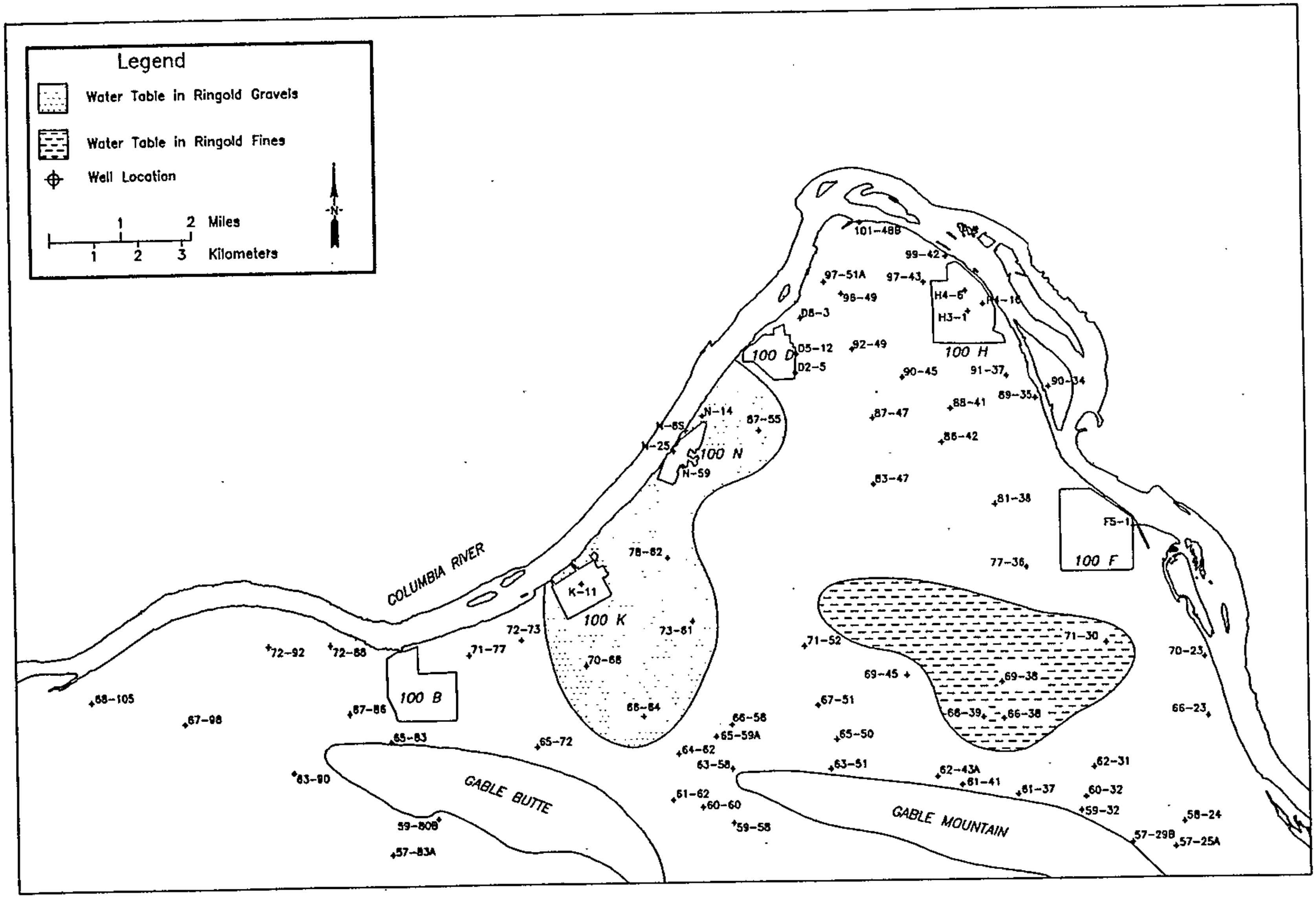

Figure 4.3-9. Geologic units intersected by the water table in the 100 Areas (modified from Lindsey 1992).

and beyond (Kasza et al. 1994). Water levels are expected to continue to decrease as the unconfined groundwater system reaches equilibrium with the new level of artificial recharge (Wurstner and Freshley 1994).

Changes vary between the 200 West and 200 East Areas in part because the water table occurs in different units with different hydraulic properties. In the 200 West Area, the water table occurs primarily in Ringold Unit E, while in the 200 East Area, it occurs primarily in the Hanford formation. Ringold Unit E generally has a lower hydraulic conductivity than the Hanford formation. On the north side of the 200 East Area, there is evidence of erosion of the uppermost basalt unit down to the Rattlesnake Ridge Interbed, allowing communication between the unconfined and uppermost confined basalt aquifer (Graham et al. 1984; Jensen 1987).

A number of reports dealing with the hydrogeology of the 200 Areas have been released including the following: Connelly et al. (1992a,b), Jackson (1992), Kasza et al. (1991), Last et al. (1989), Newcomer et al. (1992), and Swanson et al. (1992).

4.3.6 300 Area Hydrology

The unconfined aquifer water table in the 300 Area is generally found in the Ringold Formation at a depth of 9 to 19 m (30 to 62 ft) below ground surface. Fluctuations in the river level strongly affect the groundwater levels and flow in the 300 Area, just as they do in the 100 Areas. Groundwater flows from the northwest, west, and even the southwest to discharge into the Columbia River near the 300 Area. Schalla et al. (1988) and Swanson (1992) have provided more detailed information on the hydrogeology of the 300 Area.

4.3.7 1100 and Richland North Areas Hydrology

The groundwater in the southeastern portion of the Hanford Site is less impacted by Hanford Site operations than by other activities. In addition to natural recharge, artificial recharge is associated with the North Richland recharge basins (used to store Columbia River water for Richland water use) south of the 1100 Area, and irrigated farming near the Richland North Area and west and southwest of the 1100 Area. Although pumping to obtain water also occurs from the unconfined aquifer in these areas, there is a mound in the water table beneath the Richland city system of recharge basins. The Richland city recharge basins are used primarily as a backup system between January and March each year when the filtration plant is closed for maintenance, and during the summer months to augment the city's river-water supply. The water level also rose from December 1990 and December 1991 in the area of the Lamb-Weston Potato-Processing Plant, which uses large amounts of water and, except for plant maintenance during July, operates year-round. The water table in the 1100 Area seems to reflect irrigation cycles connected with agriculture and the growing season (Newcomer et al. 1992).

4.4 Environmental Monitoring

The DOE has conducted an environmental monitoring program at the Hanford Site for the past 49 years. The monitoring results have been recorded from 1946 to 1958 in quarterly reports. Since 1958, the results have been available as annual reports (summarized by Soldat et al. 1986). For calendar year 1993, the monitoring results for offsite and onsite environs and for onsite groundwater are combined in one report (Dirkes et al. 1994).

Radioactive materials in air were sampled continuously on the Hanford Site, at the Hanford Site perimeter, and in nearby and distant communities in the Columbia Basin in a total of 76 locations. The air pathway sampling resulted in a potential dose to the maximally exposed individual that was 0.2% of the EPA limit of 10 millirem (mrem)/yr (40 CFR 61) (Dirkes et al. 1994).

Groundwater was collected from 770 wells in 1993 that sampled both the confined and unconfined aquifers beneath the Hanford Site. The major plume of ^{3}H-contaminated groundwater continued to move eastward, resulting in seepage into the Columbia River. Samples of Columbia River water were collected immediately upstream and downstream of the Hanford Site. Concentrations of all radionuclides observed in river water were all well below applicable EPA and state of Washington DWS (Dirkes et al. 1994).

Foodstuffs from the area, including those irrigated with Columbia River water, were sampled. Although concentrations of most specific radionuclides were below detectable limits, low levels of ^{3}H, ^{90}Sr, ^{129}I, and ^{137}Cs were found in a number of foodstuffs collected in 1993. Details can be found in Dirkes et al. (1994).

Deer, rabbits, game birds, waterfowl, and fish were also collected and analyzed; results were similar to those in recent years (Dirkes et al. 1994). Deer, game birds, waterfowl, and fish showed low levels of ^{137}Cs attributable to Hanford operations. Other concentrations of radionuclides were typical of levels attributable to worldwide weapon-test fallout. Full details can be found in Dirkes et al. (1994).

Low concentrations of radionuclides were measured in samples of soil and vegetation during 1993. Onsite mean concentrations of ^{238}U in soil and vegetation were lower in 1993 than in 1992, whereas ^{137}Cs concentrations were higher. The levels were similar to those obtained in previous years, and no discernible increase in concentration could be attributed to current Hanford operations. Dose rates from external penetrating radiation measured near local residential areas were similar to those observed in previous years, and no contribution from Hanford activities could be identified (Dirkes et al. 1994).

Certain chemicals for which DWS have been set by the EPA and the state of Washington were also present in Hanford groundwater near operating areas. The following summary of chemical concentrations is from Dirkes et al. (1994). Nitrate was measured at concentrations greater than the DWS (45 mg/L as nitrate ion) in wells in all operational areas except the 100-B, 300, and 400 Areas. Nitrate concentrations greater than DWS were widespread in groundwater beneath the 200 West Area and adjacent parts of the 600 Area. Fluoride was detected at levels greater than the primary DWS (4.0 mg/L) in the 200 West Area and greater than the secondary standard (2.0 mg/L) in the 200 East and 200 West Areas. Chromium contamination is widespread in the groundwater throughout the

Hanford Site, often in concentrations exceeding DWS. Carbon tetrachloride contamination was found in the unconfined aquifer beneath much of the 200 West Area. The distribution of carbon tetrachloride in the 200 West Area has remained relatively stable since its existence was first noted in 1987. In addition to carbon tetrachloride, significant amounts of other chlorinated hydrocarbon solvents were found in 200 West Area groundwater, including trichloroethylene and chloroform. Tetrachloroethylene, also referred to as perchloroethylene, is found at levels greater than the DWS in a number of areas of the Site.

Measured and calculated radiation doses to the general public from Hanford operations were well below applicable regulatory limits throughout 1993. The potential dose to the hypothetical maximally exposed individual from 1993 operations was about 0.03 mrem, 0.01 mrem higher than reported for 1992, and the same as reported for the 1991 dose. The potential dose to the local population of 380,000 persons was 0.4 person-rem as compared with 0.8 person-rem in 1992 (Dirkes et al. 1994). The 1993 average dose to the population was 0.001 mrem. These doses are much lower than doses potentially received by the general public from other common sources of radiation (Figure 4.4-1). The current DOE radiation limit for an individual member of the public is 100 mrem/yr, and the average dose from natural sources is 300 mrem/yr (Dirkes et al. 1994).

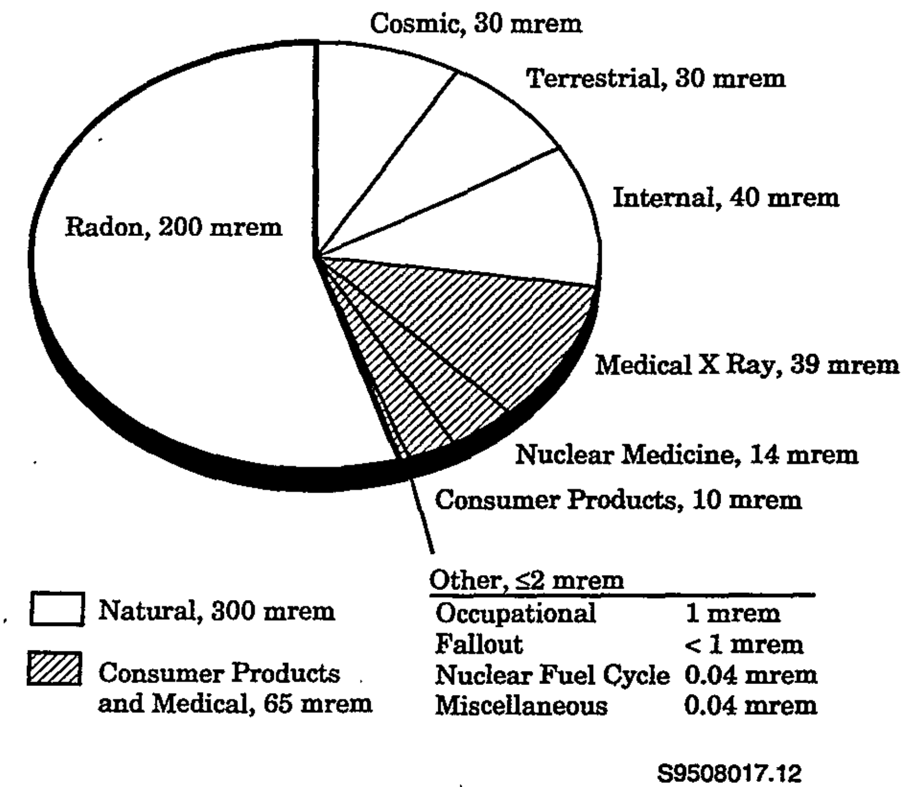

Figure 4.4-1. Annual radiation doses from various sources (NCRP 1987).

4.5 Ecology

The Hanford Site encompasses 1450 km^2 (560 mi^2) of shrub-steppe habitat that is adapted to the region's mid-latitude semiarid climate (Critchfield 1974). The Site encompasses undeveloped land interspersed with industrial development along the western shoreline of the Columbia River and at several locations in the interior of the Site. The developed portion of the Site accounts for approximately 6% of the total available land area and is interconnected by roads, railroads, and electrical transmission lines. Operation of the Site infrastructure contributes to the primary Site mission of clean up.

The Hanford Site is characterized as a shrub-steppe ecosystem (Daubenmire 1970). Such ecosystems are typically dominated by a shrub overstory with a grass understory; in the early 1800s, dominant plants in the area were big sagebrush underlain by perennial Sandberg's bluegrass and bluebunch wheatgrass. With the advent of settlement, livestock grazing and agricultural production contributed to colonization by nonnative vegetation species that currently dominate the landscape. Although agriculture and livestock production were the primary subsistence activities at the turn of the century, these activities ceased when the Site was designated in 1943.

The Hanford Site is bordered to the east by the Columbia River. Operation of Priest Rapids Dam upstream of the Site accommodates maintenance of intakes at the Hanford Site and contributes to management of anadromous fish populations. The Columbia River provides habitat for various wildlife and vegetation species as well as recreation and commercial navigation.

Several areas, totalling 655 km^2 (257 mi^2), on the Site have been designated for research or as wildlife refuges. These include the ALE Reserve, the U.S. Fish and Wildlife Service Saddle Mountain National Wildlife Refuge, and the Washington State Department of Fish and Wildlife Wahluke Slope Wildlife Area.

Other descriptions of the ecology of the Hanford Site can be found in Cadwell (1994), Downs et al. (1993), ERDA (1975), Jamison (1982), Rogers and Rickard (1977), Sackschewsky et al. (1992), Watson et al. (1984), and Weiss and Mitchell (1992).

4.5.1 Terrestrial Ecology

4.5.1.1 Vegetation

The distribution and dominance of endemic species on the Hanford Site have been altered largely by Eurasian human activities that have resulted in a standing crop of predominately nonnative species. Of the 590 species of vascular plants recorded for the Hanford Site, approximately 20% of all species are considered nonnative (Sackschewsky et al. 1992). The dominant species, cheatgrass, is an aggressive colonizer and has become well established across the Site (Rickard and Rogers 1983). Compared with other semiarid regions in North America, primary productivity is relatively low. This difference is attributed to low annual precipitation (16 cm [6.3 in.]), low water-holding capacity of the rooting substrate (sand), and droughty summers and cold winters. Many species are adapted to wildfire that historically burned through the area during the dry summers.

Vegetation and land use areas that occur across the Hanford Site are illustrated in Figure 4.5-1. A narrow definition of these types includes shrub-steppe on slopes, shrub-steppe on the Columbia River Plain, recovering shrub-steppe on the Columbia River Plain, hopsage-greasewood, abandoned fields, riparian, sand dunes, bunchgrass, cheatgrass, winterfat, Sandberg's bluegrass, and basalt outcrops (Figure 4.5-1). A list of common plant species to these types are presented in Table 4.5-1. A much broader definition of these types including shrublands, grasslands, tree zones, riparian, and unique habitat follows.

Shrublands. Shrublands occupy the largest area in terms of acreage and comprise seven of the nine major plant communities on the Hanford Site (Sackschewsky et al. 1992). Of the shrubland types, sagebrush-dominated communities are the predominant type, with other shrub communities varying with changes in soil and elevation.

The area botanically characterized as shrub-steppe includes remnant native big sagebrush, three-tip sagebrush, antelope bitterbrush, gray rabbitbrush, and spiny hopsage. Remnant bluebunch wheatgrass, Sandberg's bluegrass, needle-and-thread grass, Indian ricegrass, and prairie junegrass also occur in this vegetation type. Heterogeneity of species composition varies with soil, slope, and elevation. Of the vegetation types depicted in Figure 4.5-1, the following species associations have been recorded: shrub-steppe on slopes includes big sagebrush or three-tip sagebrush with an understory of bluebunch wheatgrass; shrub-steppe on the Columbia River Plain includes big sagebrush and/or bitterbrush with cheatgrass or Sandberg's bluegrass; and recovering shrub-steppe on the Columbia River Plain refers to areas impacted by wildfire that have become colonized by cheatgrass and tumbleweed.

Grasslands. Most grasses occur as understory in shrub-dominated plant communities. Cheatgrass has replaced many native perennial grass species and is well established in many low-elevation (<244 m [800 ft]) and/or disturbed areas (Rickard and Rogers 1983). Of the native grasses that occur on the Site, bluebunch wheatgrass occurs at higher elevations. Sandberg's bluegrass is more widely distributed and occurs within several plant communities. Needle-and-thread grass and thickspike wheatgrass occur in sandy soils typical of dune habitat. Species preferring more moist locations include bentgrass, meadow foxtail, lovegrasses, and reed canarygrass (Mazaika et al. In prep.)[a].

Tree Zones. Trees afford unique attributes of terrestrial habitat on the Hanford Site. Before settlement, the landscape lacked trees, which were planted by homesteaders in association with agricultural areas. Currently, approximately 23 species of trees occur on the Site. The most commonly occurring species are black locust, Russian olive, cottonwood, mulberry, sycamore, and poplar. Many of these nonnative species are aggressive colonizers and have become established along the Columbia River (e.g., cottonwood, poplar, Russian olive), serving as a functional component of the riparian zone (Mazaika et al. In prep.)[a].

(a) Mazaika, R., C. McAllister, K. Cadwell, C. Abrams, K. Miller, S. Friant, and G. Bilyard. 1995. Draft Survey of Ecological Resources at Selected U.S. Department of Energy Sites. In preparation, Pacific Northwest Laboratory, Richland, Washington.

Vegetation/Land Use Cover Map for the Hanford Site
(March 1, 1995, Rev. 1)*

1) Shrub-Steppe on Slopes
2) Shrub-Steppe on the Columbia River Plain/Uplands
3) Recovering Shrub-Steppe on the Columbia River Plain/Uplands
4) Bunchgrasses on Slopes
5) Hopsage/Greasewood
6) Cheatgrass
7) Abandoned Fields
8) Riparian
9) Agricultural Areas
10) Sand Dunes
11) Disturbed/Facilities
12) Water
13) Basalt Outcrops

* Based on 1987 and 1991 aerial photography. Map subject to revision.
Files: habitat.13 (3/1/95, mas)

Figure 4.5-1. Distribution of vegetation types and land use areas on the Hanford Site.

Table 4.5-1. Common vascular plants on the Hanford Site.

A. Shrub-Steppe Species	Scientific Name
Shrub	
Big sagebrush	*Artemisia tridentata*
Bitterbrush	*Purshia tridentata*
Gray rabbitbrush	*Chrysothamnus nauseosus*
Green rabbitbrush	*Chrysothamnus viscidiflorus*
Snow buckwheat	*Eriogonum niveum*
Spiny hopsage	*Grayia (Atriplex) spinosa*
Perennial Grasses	
Bluebunch wheatgrass	*Agropyron spicatum*
Bottlebrush squirreltail	*Sitanion hystrix*
Crested wheatgrass	*Agropyron desertorum (cristatum)*[a]
Indian ricegrass	*Oryzopsis hymenoides*
Needle-and-thread grass	*Stipa comata*
Sand dropseed	*Sporobolus cryptandrus*
Sandberg's bluegrass	*Poa sandbergii (secunda)*
Thickspike wheatgrass	*Agropyron dasytachyum*
Perennial Forbs	
Bastard toad flax	*Comandra umbellata*
Buckwheat milkvetch	*Astragalus caricinus*
Carey's balsamroot	*Balsamorhiza careyana*
Cusick's sunflower	*Helianthus cusickii*
Cutleaf ladysfoot mustard	*Thelypodium laciniatum*
Douglas' clusterlily	*Brodiaea douglasii*
Dune scurfpea	*Psoralea lanceolata*
Franklin's sandwort	*Arenaria franklinii*
Gray's desertparsley	*Lomatium grayi*
Hoary aster	*Machaeranthera canescens*
Longleaf phlox	*Phlox longifolia*
Munro's globemallow	*Sphaeralcea munroana*
Pale eveningprimrose	*Oenothera pallida*
Sand beardtongue	*Penstemon acuminatus*
Stalked-pod milkvetch	*Astragalus sclerocarpus*
Threadleaf fleabane	*Erigeron filifolius*
Turpentine spring parsley	*Cymopteris terebinthinus*

Table 4.5-1. (Cont'd)

A. Shrub-Steppe Species	Scientific Name
Perennial Forbs (contd)	
Winged dock	*Rumex venosus*
Yarrow	*Achillea millefolium*
Yellow bell	*Fritillaria pudica*
Annual Forbs	
Annual Jacob's ladder	*Polemonium micranthum*
Blue mustard	*Chorispora tenella*[a]
Bur ragweed	*Ambrosia acanthicarpa*
Clasping pepperweed	*Lepidium perfoliatum*
Hoary falseyarrow	*Chaenactis douglasii*
Indian wheat	*Plantago patagonica*
Jagged chickweed	*Holosteum umbellatum*[a]
Jim Hill's tumblemustard	*Sisymbrium altissimum*[a]
Matted cryptantha	*Cryptantha circumscissa*
Pink microsteris	*Microsteris gracilis*
Prickly lettuce	*Lactuca serriola*[a]
Rough wallflower	*Erysimum asperum*
Russian thistle (tumbleweed)	*Salsola kali*[a]
Slender hawksbeard	*Crepis atrabarba*
Spring whitlowgrass	*Draba verna*[a]
Storksbill	*Erodium cicutarium*[a]
Tall willowherb	*Epilobium paniculatum*
Tarweed fiddleneck	*Amsinckia lycopsoides*
Threadleaf scorpion weed	*Phacelia linearis*
Western tansymustard	*Descurainia pinnata*
White cupseed	*Plectritis macrocera*
Whitestem stickleaf	*Mentzelia albicaulis*
Winged cryptantha	*Cryptantha pterocarya*
Yellow salsify	*Tragopogon dubius*[a]
Annual Grasses	
Cheatgrass	*Bromus tectorum*[a]
Slender sixweeks	*Festuca octoflora*
Small sixweeks	*Festuca microstachys*

Table 4.5-1. (Cont'd)

B. Riparian Species	Scientific Name
Trees and Shrubs	
Black cottonwood	*Populus trichocarpa*
Black locust	*Robinia pseudo-acacia*
Coyote willow	*Salix exigua*
Dogbane	*Apocynum cannabinum*
Peach, apricot, cherry	*Prunus* spp.
Peachleaf willow	*Salix amygdaloides*
Willow	*Salix* spp.
White Mulberry	*Morus alba*[a]
Perennial Grasses and Forbs	
Blanket flower	*Gaillardia aristata*
Bulrushes	*Scirpus* spp.[b]
Cattail	*Typha latifolia*[b]
Columbia River gumweed	*Grindelia columbiana*
Hairy golden aster	*Heterotheca villosa*
Heartweed	*Polygonum persicaria*
Horsetails	*Equisetum* spp.
Horseweed tickseed	*Coreopsis atkinsoniana*
Lupine	*Lupinus* spp.
Pacific sage	*Artemisia campestris*
Prairie sagebrush	*Artemisia ludoviciana*
Reed canary grass	*Phalaris arundinacea*[b]
Rushes	*Juncus* spp.
Russian knapweed	*Centaurea repens*[a]
Sedge	*Carex* spp.[b]
Water speedwell	*Veronica anagallis-aquatica*
Western goldenrod	*Solidago occidentalis*
Wild onion	*Allium* spp.
Wiregrass spikerush	*Eleocharis* spp.[b]
Aquatic Vascular	
Canadian waterweed	*Elodea canadensis*
Columbia yellowcress	*Rorippa columbiae*
Duckweed	*Lemna minor*

Table 4.5-1. (Cont'd)

B. Riparian Species (contd)	Scientific Name
Aquatic Vascular (contd)	
Pondweed	*Potamogeton* spp.
Spiked water milfoil	*Myriophyllum spicatum*
Watercress	*Rorippa nasturtium-aquaticum*

(a) Exotic.
(b) Perennial grasses and graminoids.

Riparian Areas. Riparian habitat includes sloughs, backwaters, shorelines, islands, and palustrine areas associated with the Columbia River flood plain. Vegetation that occurs along the river shoreline includes emergent water milfoil, water smartweed, pondweed, sedge, reed canarygrass, and bulbous bluegrass. Trees include willow, mulberry, and Siberian elm. Other riparian vegetation occurs in association with perennial springs and seeps and artificial ponds and ditches on the Hanford Site. Rattlesnake and Snively springs are highly diverse biologic communities (Cushing and Wolf 1984) that support bulrush, spike rush, and cattail. Watercress, which persists at these sites, is also abundant for a large portion of the year. Artificial habitats are formed by a release of water used in the industrial processes at Hanford facilities. These habitats are ephermal, although they have contributed to the establishment of cattail, reed canarygrass, willow, cottonwood, and Russian olive in areas otherwise devoid of riparian species.

Emergent riparian (wetland) habitat that occurs in association with the Columbia River includes riffles, gravel bars, oxbow ponds, backwater sloughs, and cobble shorelines. These emergent habitats occur infrequently along the Hanford Reach and have acquired ecological significance because of the net loss of wetland habitat elsewhere within the region. Emergent species include reed canarygrass, common witchgrass, and large barnyard grass. Rushes and sedges occur along the shorelines of several sloughs along the Hanford Reach at White Bluffs, below the 100-H Area, downstream of the 100-F Area, and the Hanford Slough.

Unique Habitats. Unique habitats on the Hanford Site include bluffs, dunes, and islands. The White Bluffs, Umtanum Ridge, and Gable Mountain on the Hanford Site include rock outcrops that generally do not occur on the Site. Basalt outcrops are most often occupied by plant communities dominated by buckwheat and Sandberg's bluegrass.

The terrain of the dune habitat rises and falls between 3 and 5 m (10 and 16 ft) aboveground, creating areas that range from 2.5 to several hundred acres in size (U.S. Department of the Army 1990). The dunes are vegetated by bitterbrush, scurfpea, and thickspike wheatgrass.

Island habitat accounts for approximately 1170 acres (Hanson and Browning 1959) and 64.3 km (39.9 mi) of river shoreline within the main channel of the Hanford Reach. Shoreline riparian vegetation that characterizes the islands includes willow, poplar, Russian olive, and mulberry. Species occurring on the island interior include buckwheat, lupine, mugwort, thickspike wheatgrass, giant wildrye, yarrow, and cheatgrass (Warren 1980). Management of these islands is a shared responsibility of the DOE, the U.S. Fish and Wildlife Service, and the U.S. Bureau of Land Management.

Operable Units. In general, the operable units are typified by nonnative or invasive vegetation species. Cheatgrass, Russian thistle, and tumble mustard are invasive species that have colonized many of the disturbed portions of these sites. The 100 Area operable units are characterized by a narrow band of riparian vegetation along the shoreline of the Columbia River, with much of the area shoreward consisting of old agricultural fields, dominated by cheatgrass and tumble mustard. Scattered big sagebrush and gray rabbitbrush also occur throughout the 100 Areas (Landeen et al. 1993). Waste management areas, reactors, and crib sites are generally vegetated by noxious or invasive species including Russian thistle, tumble mustard, and cheatgrass. Russian thistle and gray rabbitbrush that occur in these areas are deep rooted and have the potential to uptake radionuclides and other contaminants, functioning as a pathway to other parts of the ecosystem (Landeen et al. 1993). Federal and state threatened or endangered species that have been reported for the 100 Area operable units include Columbia yellowcress, southern mugwort, false pimpernel, shining flatsedge, gray cryptantha, and possibly dense sedge (Landeen et al. 1993). Most of these species are located near the 100-B/C Area wetland.

Plant species of interest and their potential as pathways for contaminant transport of radionuclides or metals include reed canarygrass (low), water milfoil (low, metals elevated), asparagus (low, elevated zinc), and mulberry (low, elevated cesium, ^{90}Sr, magnesium, and potassium). For a description of relative concentration, see Landeen et al. (1993).

The 200 Areas are characterized according to the sagebrush/cheatgrass or Sandberg's bluegrass communities of the 200 Area Plateau. The dominant plants on the 200 Area Plateau are big sagebrush, rabbitbrush, cheatgrass, and Sandberg's bluegrass, with cheatgrass providing half of the total plant cover.

Vegetation surveys were conducted at the 300-FF-5 Operable Unit during 1992. The shrubsteppe vegetation community in the unit is characterized by antelope bitterbrush/Sandberg's bluegrass with an overstory of bitterbrush and big sagebrush and an understory of cheatgrass and Sandberg's bluegrass (Brandt et al. 1993). Dominant riparian vegetation in the unit included white mulberry and shrub willow, reed canarygrass and bulbous bluegrass, and sedges and horsetail. Columbia yellowcress, a state species of concern, was identified at 18 locations near this operable unit. Riparian plants have the greatest potential to make root contact with contaminated groundwater.

4.5.1.2 Wildlife

Included in the 240 species of terrestrial vertebrates observed on the Hanford Site are approximately 40 species of mammals, 187 species of birds, 3 species of amphibians, and 9 species of reptiles.

All terrestrial habitats, including riparian areas along the Columbia River, shrub- and grasslands, canyons, basalt outcrops, cliffs, and facilities of the operable units are important to terrestrial species.

Insects, reptiles, and amphibians occur throughout most habitats on the Hanford Site and are discussed briefly herein. Grasshoppers and darkling beetles are among the more conspicuous of the approximately 600 species of insects that have been found on the Hanford Site. Most species of darkling beetle occur throughout the spring to fall, although some species are present during several months in the fall (Rogers and Rickard 1977). Grasshoppers are evident during late spring through fall. The side-blotched lizard is the most abundant reptile species that occurs on the Hanford Site. Short-horned and sagebrush lizards are reported for the Site, but occur infrequently. The most common snake species include gopher snake, yellow-bellied racer, and Pacific rattlesnake. Western toads and frogs are the most common amphibian species and occur near permanent water bodies along the Hanford Reach.

Shrubland and Grassland Wildlife. All major groups of terrestrial wildlife, except amphibians, occur in the shrub- and grassland habitat. Common species include Rocky Mountain elk and mule deer; coyotes, bobcat, and badgers; and several species of microtenes including deer mice, harvest mice, grasshopper mice, ground squirrels, voles, and black-tailed jackrabbits. The most abundant mammal on the Site is the Great Basin pocket mouse.

Mule deer are reliant, at least for a portion of the year, on bitterbrush shrubs for browse. Elk, which are more dependant on open grasslands for forage seek the cover of sagebrush and other shrub species during the summer months. Elk, which first appeared on the Hanford Site in 1972 (Fitzner and Gray 1991), have increased from approximately 8 animals in 1975 to approximately 300 in 1994. The herd of elk that inhabits the Hanford Site occupies the ALE Reserve and private lands that adjoin the reserve to the north and west.

Shrub- and grasslands provide nesting and foraging habitat for many passerine species. Surveys conducted during 1993 (Cadwell 1994) reported the occurrence of western meadowlarks and horned larks more frequently in shrubland habitats than in other habitats on the Site. Long-billed curlews and vesper sparrows were also noted as commonly occurring species in shrubland habitat. Species that are dependant on undisturbed shrub habitat include sage sparrow, sage thrasher, and loggerhead shrike. Both the sage sparrow and loggerhead shrike tend to roost and nest in sagebrush or bitterbrush that occurs at lower elevations (Mazaika et al. In prep)[a]. Ground-nesting species that occur in grass-covered uplands include long-billed curlews and burrowing owls. These areas provide nesting, foraging, and loafing habitat for these species.

Common upland species that occur in shrub- and grassland habitat include chukar partridge, California quail, and Chinese ring-necked pheasant. Chukar are most numerous in the Rattlesnake

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(a) Mazaika, R., C. McAllister, K. Cadwell, C. Abrams, K. Miller, S. Friant, and G. Bilyard. 1995. *Draft Survey of Ecological Resources at Selected U.S. Department of Energy Sites*. In preparation, Pacific Northwest Laboratory, Richland, Washington.

Hills, Yakima Ridge, Umtanum Ridge, Saddle Mountains, and Gable Mountain areas of the Hanford Site. Less common species include western sage grouse, Hungarian partridge, and scaled quail. Western sage grouse were historically abundant on the Hanford Site; however, populations have declined since the early 1800s because of the conversion of sagebrush-steppe habitat. Surveys conducted by the Washington Department of Fish and Wildlife and the Pacific Northwest Laboratory during late winter and early spring 1993 did not reveal presence of western sage grouse in sagebrush-steppe habitat of the ALE Reserve (Cadwell 1994).

Among the more common raptor species that use shrub- and grassland habitat are ferruginous hawks, Swainson's hawk, and red-tailed hawk. Northern harriers, sharp-shinned hawks, rough-legged hawks, and golden eagles also occur in these habitats but are not noted as frequently. In 1994, nesting by red-tailed, Swainson's, and ferruginous hawks included 41 nests located across the Hanford Site in relation to high voltage transmission towers, trees, cliffs, and basalt outcrops. In recent years the number of nesting ferruginous hawks on the Hanford Site has increased, as a result in part to their acceptance of steel powerline towers in the open grass- and shrubland habitats.

A cooperative research effort between the Pacific Northwest Laboratory and the Washington Department of Fish and Wildlife is examining home range and habitat use of ferruginous hawks on the Site, in an effort to understand the species success in a region where population numbers are, generally, in decline.

Tree Zone Wildlife. Trees occur infrequently on the Hanford Site but provide nesting habitat and thermal cover for many species of mammals and raptors. Raptors use trees for nesting, perching, and roosting. Ferruginous and Swainson's hawks use trees for nesting and perching. During 1994, two ferruginous hawk nests and 17 Swainson's hawk nests were located in trees on the Hanford Site. Bald eagles that occur along the Hanford Reach of the Columbia River use trees for daytime perching and, in some cases, communal night roosts. Great blue herons and black crowned night herons are associated with trees in riparian habitat along the Columbia River and use groves or individual trees for perching, nesting, or rookeries. During 1993, three great blue heron rookeries were located on the Hanford Site within the Hanford Reach (Cadwell 1994).

Riparian Wildlife. Shoreline riparian communities are seasonally important for a variety of species. Willow trap food for waterfowl (i.e., Canada geese) and birds that use shoreline habitat (i.e., Forster's tern) and provide nesting habitat for passerines (i.e., mourning doves). Terrestrial and aquatic insects are abundant in emergent grasses and provide forage for fish, waterfowl, and shorebirds. Beaver and mule deer rely on shoreline habitat for foraging. Riparian areas provide nesting and foraging habitat and escape cover for many species of birds and mammals.

Mammals that rely on riparian vegetation include rodents, bats, furbearers (e.g., mink and weasels), porcupine, raccoon, skunk, and mule deer. During the summer months, mule deer rely on riparian vegetation for foraging and periodically will cross the Columbia River to access islands or the eastern shorelines. Riparian areas afford suitable habitat for insectivorous bats. The Columbia River and Rattlesnake Springs provide foraging habitat for most species of bats including myotis, small-footed myotis, silver-haired bats, and pallid bats (Becker 1993).

The most common bird species that occur in riparian habitats include American robin, black-billed magpie, song sparrow, and dark-eyed junco (Cadwell 1994). Upland gamebirds that use this habitat include chukars and California quail. Predatory birds include common barn owl, northern saw-shet owl, and great horned owl. Species known or expected to nest in riparian habitat are Brewer's blackbird, mourning dove, black-billed magpie, northern oriole, lazuli bunting, orange-crowned warbler, eastern and western kingbird, and western wood peewee. Bald eagles, which have wintered on the Hanford Site since 1960, rely on riparian habitat along the shoreline of the Columbia River.

The Hanford Site is located in the Pacific Flyway, and the Hanford Reach serves as a resting area for migratory waterfowl and shorebirds. During the fall and winter months, ducks (primarily mallards) and Canada geese rest on the shorelines and islands along the Hanford Reach. The area between the Old Hanford Townsite and Vernita Bridge is closed to recreational hunting, and large numbers of migratory waterfowl find refuge in this portion of the river. Other species observed during this period include white pelicans, double-crested cormorants, and common loons.

Wildlife Occurring in Unique Habitat. Bluffs provide perching, nesting, and escape habitat for several species on the Hanford Site. The White Bluffs and Umtanum Ridge provide nesting habitat for prairie falcons, red-tailed hawks, cliff swallows, bank swallows, and rough-winged swallows. In the past, Canada geese used the lower elevations of White Bluffs for nesting and brooding. Bluff areas provide habitat for sensitive species (i.e., Hoover's desert parsley and peregrine falcon) that otherwise may be subject to impact from frequent or repeated disturbance.

Dune habitat is unique in its association with the surrounding shrub-steppe vegetation type. The uniqueness of the dunes is noted in its vegetation component as well as the geologic formation. The terrain of the Hanford dunes provides habitat for mule deer, burrowing owls, and predatory coyotes as well as many transient species.

Islands afford a unique arrangement of upland and shoreline habitat for avian and terrestrial species. Islands vary in soil type and vegetation and range from narrow cobble benches to extensive dune habitats. With exception for several plant species, the islands accommodate many of the same species that occur in mainland habitats. Operation of Priest Rapids Dam upstream of the Hanford Reach creates daily and seasonal fluctuations in river levels, which may limit community structure and overall shoreline species viability along the shoreline interface.

Islands provide resting, nesting, and escape habitat for waterfowl and shorebirds. Use of islands for nesting by Canada geese has been monitored since 1950. The suitability of habitat for nesting Canada geese is attributed to restricted human use of islands during the nesting season, suitable substrate, and adequate forage and cover for broods (Eberhardt et al. 1989). The nesting population has fluctuated in relation to coyote predation, which has been attributed as the major cause of decline of geese in the Hanford Reach in recent years. During 1993, 196 of 235 pairs of geese nested in the Hanford Reach, compared with 213 of 286 pairs that nested successfully in 1992 (Cadwell 1994). Control programs have been implemented in the past to control coyote population numbers. Islands also accommodate colonial nesting species including California gulls, ring-billed gulls, Forster's terns, and great blue herons. Again, extensive areas ranging from 30 to 50 acres accommodate colonial nesting species that may range in population size of upwards of 2000 individuals.

Wildlife Occurring at the Operable Units. Insects, reptiles, amphibians, birds, and mammals that occur in the 100, 200, and 300 Area operable units, in general, are typical of species that occur across the Site. During 1991 to 1993, surveys for birds, mammals, insects, and vegetation were conducted at several of the 100 and 300 Area operable units (Brandt et al. 1993; Landeen et al. 1993).

Landeen et al. (1993) conducted surveys at the 100 Area operable units between 1991 and 1992. One hundred seven bird species were recorded during the 1991/1992 surveys. Of the 29 mammal species known to occur in the 100 Area operable units, 11 were observed during 1991/1992. Species of special concern that use the operable units include the American white pelican, bald eagle, peregrine falcon, mule deer, coyote, Great Basin pocket mouse, black-tailed jackrabbit, and Nuttall's cottontail (Landeen et al. 1993). An assessment of potential contamination and exposure pathways of species of special concern that occur in the 100 Area operable units includes consumption of flying insects (low); mud-nest building behavior (low); vegetation consumption (low); soil excavation (elevated); consumption of vegetation, small mammals, or birds (localized, low); and consumption of aquatic periphyton (trace) (Landeen et al. 1993). See Table 4.5-2 for more information.

Surveys were conducted during 1992 to determine the presence of reptile, bird, and mammal species in the 300-FF-5 Operable Unit. Reptiles and amphibians known to occur in the unit include western yellow-bellied racer, gopher snake, side-blotched lizard, sagebrush lizard, the Great Basin spadefoot toad, the western toad, Woodhouse's toad, bullfrog, and the Pacific tree frog (Brandt et al. 1993).

Fifty-three species of birds, including 14 riverine and 19 riparian species (Brandt et al. 1993) were recorded during 1992 surveys of the 300-FF-5 Operable Unit. Seven candidate species for federal or state listing as endangered or threatened were observed. These included burrowing owl, common loon, Forster's tern, great blue heron, loggerhead shrike, osprey, and sage sparrow. Fifteen species of mammals were recorded during 1992 surveys. The most abundant of species that occur in shrubsteppe habitat observed in the unit included burrowing owls, western kingbirds, white-crowned sparrows, and western meadowlarks (Brandt et al. 1993). Rock doves and European starlings are nuisance species that occur in the operable units.

Fifteen species of mammals were observed during 1992 surveys of the 300-FF-5 Operable Unit. The most frequently encountered small mammals were house mouse and Great Basin pocket mouse. Other species included deer mouse, western harvest mouse, and grasshopper mouse. Although not observed during 1992 surveys, Townsend's ground squirrel, black-tailed jackrabbit, Nuttall's cottontail, beaver, mule deer, badger, and coyote use the 300 Area Operable Unit.

Species at potential risk during operable unit remediation activities include mule deer, black-tailed jackrabbit, beaver, coyote, raccoon, house mouse, Great Basin pocket mouse, Nuttall's cottontail, beaver, bald eagle, ferruginous hawk, Swainson's hawk, loggerhead shrike, long-billed curlew, great blue heron, sage sparrow, ring-billed gull, mallard, Canada goose, northern harrier, and western meadowlark. Species ecology and pathways relative to contaminant uptake or exposure are included in Table 4.5-2 (Brandt et al. 1993).

Table 4.5-2. Avian and mammalian species and pathways for contamination in habitat of the operable units.

Species	Risk[a]
Birds	
Bald eagle	Salmon, waterfowl ingestion
Burrowing owl	Small mammals, insects ingestion
Canada goose	Vegetation ingestion
Ferruginous hawk	Small/medium mammal ingestion
Forster's tern	Nesting habitat use exposure
Great blue heron	Fish, amphibians, reptiles, invertebrates ingestion
Loggerhead shrike	Birds, mammals, insects ingestion
Long-billed curlew	Beetles, insect larvae ingestion
Mallard	Nesting habitat use exposure
Merganser	Fish ingestion
Northern harrier	Small mammals, birds ingestion
Ring-billed gull	Nesting habitat use exposure
Sage sparrow	Insects, seeds ingestion
Swainson's hawk	Reptiles, mammal ingestion
Western meadowlark	Insects, seeds ingestion
Mammals	
Beaver	Willow, cottonwood, forbs ingestion
Black-tailed jackrabbit	Yarrow, turpentine bush, mustard, buckwheat, rabbitbrush ingestion
Coyote	Mammals, birds, insects, fruits ingestion
Great Basin pocket mouse	Cheatgrass, seeds, insects ingestion
House mouse	Grass, insects ingestion
Mule deer	Forbs, shrubs, grass ingestion
Nuttall's cottontail	Sagebrush, grass, forbs ingestion
Raccoon	Invertebrates, seeds, small mammals, birds ingestion

(a) Pathway of exposure.

4.5.2 Aquatic Ecology

There are two types of natural aquatic habitats on the Hanford Site: one is the Columbia River, which flows along the northern and eastern edges of the Hanford Site, and the other is provided by the small spring-streams and seeps located mainly on the ALE Reserve (Figure 4.5-2) in the Rattlesnake Hills. Several artificial water bodies, both ponds and ditches, have been formed as a result of waste-water disposal practices associated with operation of the reactors and separation facilities. These are temporary and will vanish with cessation of activities; while present, however, they form established aquatic ecosystems (except West Pond) complete with representative flora and fauna (Emery and McShane 1980). West Pond is created by a rise in the water table in the 200 Areas and is not fed by surface flow; thus, it is alkaline and has a greatly restricted complement of biota.

4.5.2.1 Columbia River

The Columbia River is the dominant aquatic ecosystem on the Hanford Site and supports a large and diverse community of plankton, benthic invertebrates, fish, and other communities. It has a drainage area of about 680,000 km^2, an estimated average annual discharge of 6600 m^3/s, and a total length of about 2000 km ($\sim$1240 mi) from its origin in British Columbia to its mouth at the Pacific Ocean. The Columbia has been dammed both upstream and downstream from the Hanford Site, and the reach flowing through the area is the last free-flowing, but regulated, reach of the Columbia River in the United States above Bonneville Dam. Plankton populations in the Hanford Reach are influenced by communities that develop in the reservoirs of upstream dams, particularly Priest Rapids Reservoir, and by manipulation of water levels below by dam operations in downstream reservoirs. Phyto-plankton and zooplankton populations at Hanford are largely transient, flowing from one reservoir to another. There is generally insufficient time for characteristic endemic groups of phytoplankton and zooplankton to develop in the Hanford Reach. No tributaries enter the Columbia during its passage through the Hanford Site.

The Columbia River is a very complex ecosystem because of its size, the number of alterations, the biotic diversity, and size and diversity of its drainage basin. Streams in general, especially smaller ones, usually depend on organic matter from outside sources (terrestrial plant debris) to provide energy for the ecosystem. Large rivers, particularly the Columbia River with its series of large reservoirs, contain significant populations of primary energy producers (algae and plants) that contribute to the basic energy requirements of the biota. Phytoplankton (free-floating algae) and periphyton (sessile algae) are abundant in the Columbia River and provide food for herbivores such as immature insects, which in turn are consumed by carnivorous species. Figure 4.5-3 is a simplified diagram of the food web relationships in selected Columbia River biota and represents probable major energy pathways.

Phytoplankton. Phytoplankton species identified from the Hanford Reach include diatoms, golden or yellow-brown algae, green algae, blue-green algae, red algae, and dinoflagellates. Diatoms are the dominant algae in the Columbia River phytoplankton, usually representing more than 90% of the populations. The main genera include *Asterionella, Cyclotella, Fragilaria, Melosira, Stephanodiscus*, and *Synedra* (Neitzel et al. 1982a). These are typical of those forms found in lakes and ponds and originate in the upstream reservoirs. A number of algae found as free-floating species in the Hanford Reach of the Columbia River are actually derived from the periphyton; they are detached and suspended by current and frequent fluctuations of the water level.

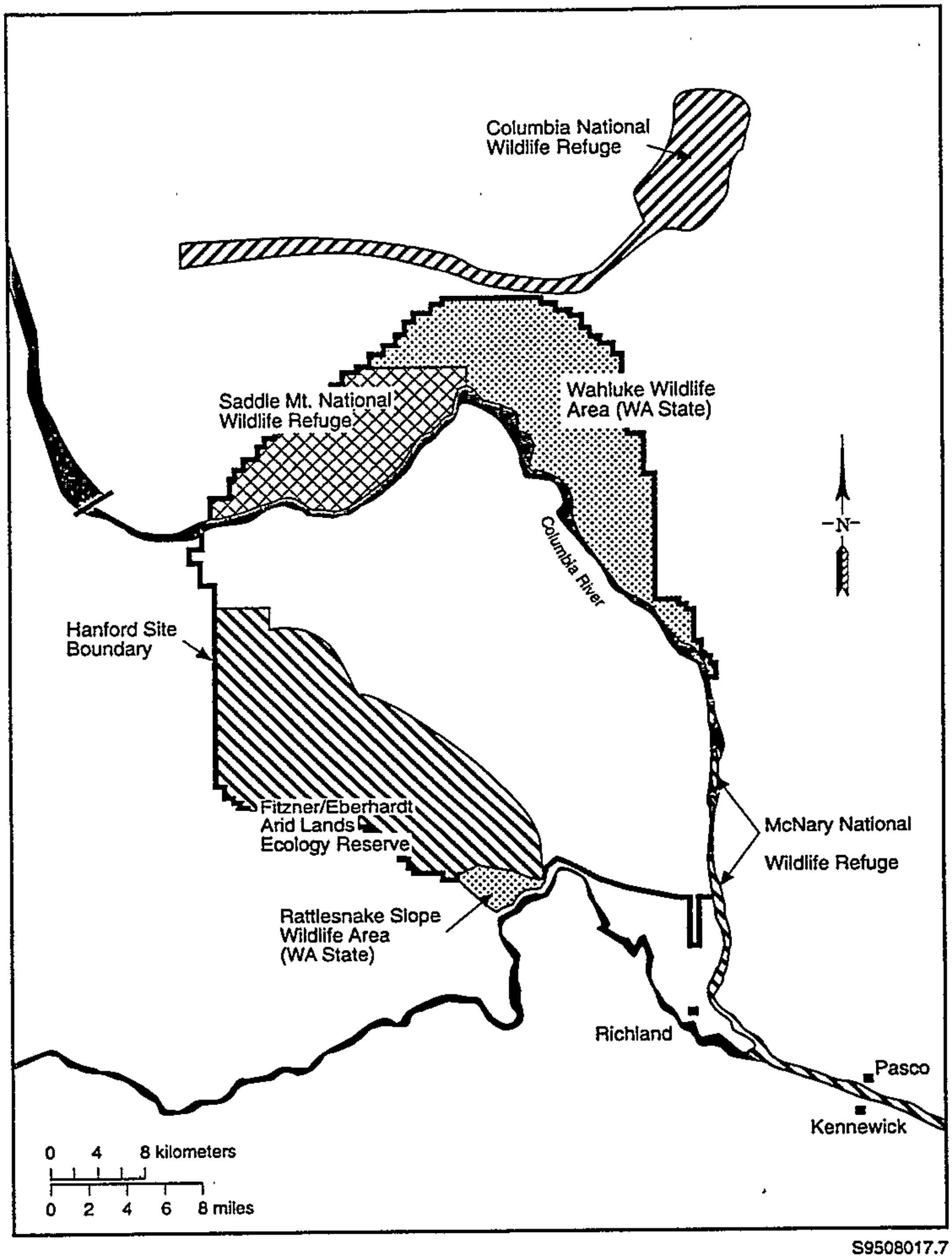

Figure 4.5-2. National and state wildlife refuges near the Hanford Site.

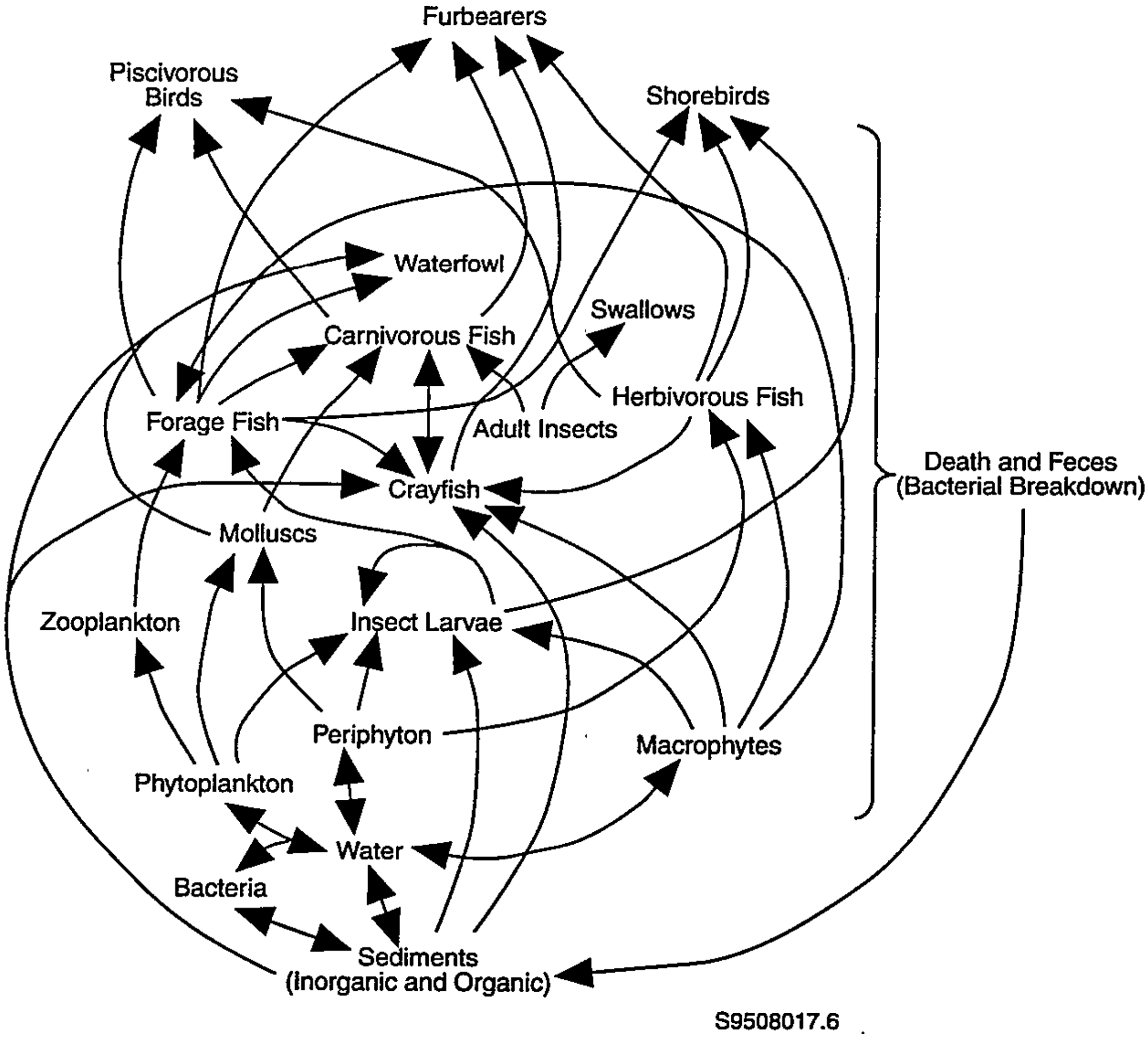

Figure 4.5-3. Interrelationships of food web components in the Columbia River ecosystem.

The peak concentration of phytoplankton is observed in April and May, with a secondary peak in late summer/early autumn (Cushing 1967a). The spring pulse in phytoplankton density is probably related to increasing light and water temperature rather than to availability of nutrients, because phosphate and nitrate nutrient concentrations are never limiting. Minimum numbers are present in December and January. Green algae (Chlorophyta) and blue-green algae (Cyanophyta) occur in the phytoplankton community during warmer months but in substantially fewer numbers than diatoms.

Diversity indices, carbon uptake, and chlorophyll-a concentrations for the phytoplankton at various times and places can be found in Beak Consultants Inc. (1980), Neitzel et al. (1982a), and Wolf et al. (1976).

Periphyton. Communities of periphytic species ("benthic microflora") develop on suitable solid substrata wherever there is sufficient light for photosynthesis. Peaks of production occur in spring and late summer (Cushing 1967b). Dominant genera are the diatoms *Achnanthes, Asterionella, Cocconeis, Fragilaria, Gomphonema, Melosira, Nitzchia, Stephanodiscus*, and *Synedra* (Beak Consultants Inc. 1980; Neitzel et al. 1982a; Page and Neitzel 1978; Page et al. 1979).

Macrophytes. Macrophytes are sparse in the Columbia River because of strong currents, rocky bottom, and frequently fluctuating water levels. Rushes (*Juncus* spp.) and sedges (*Carex* spp.) occur along shorelines of the slack-water areas such as White Bluffs Slough below the 100-H Area, the slough area downstream of the 100-F Area, and Hanford Slough. Macrophytes are also present along gently sloping shorelines that are subject to flooding during the spring freshet and daily fluctuating river levels (below Coyote Rapids and the 100-D Area). Commonly found plants include *Lemna, Potamogeton, Elodea*, and *Myriophyllum*. Where they exist, macrophytes have considerable ecological value. They provide food and shelter for juvenile fish and spawning areas for some species of warm-water game fish. However, should some of the exotic macrophytes increase to nuisance levels, they may encourage increased sedimentation of fine particulate matter. This could negatively affect the spawning of salmonids but enhance the possibility for increasing the range for shad by providing more suitable spawning habitat. These changes could have a significant impact on trophic relationships of the Columbia River.

Zooplankton. The zooplankton populations in the Hanford Reach of the Columbia River are generally sparse. In the open-water regions, crustacean zooplankters are dominant; dominant genera are *Bosmina, Diaptomus*, and *Cyclops*. Densities are lowest in winter and highest in the summer, with summer peaks dominated by *Bosmina* and ranging up to 4,500 organisms/m^3. Winter densities are generally <50 organisms/m^3. *Diaptomus* and *Cyclops* dominate in winter and spring, respectively (Neitzel et al. 1982b).

Benthic Organisms. Benthic organisms are found either attached to or closely associated with the substratum. All major freshwater benthic taxa are represented in the Columbia River. Insect larvae such as caddisflies (Trichoptera), midge flies (Chironomidae), and black flies (Simuliidae) are dominant. Dominant caddisfly species are *Hydropsyche cockerelli, Cheumatopsyche campyla*, and *C. enonis*. Other benthic organisms include limpets, snails, sponges, and crayfish. Peak larval insect densities are found in late fall and winter, and the major emergence is in spring and summer (Wolf 1976). Stomach contents of fish collected in the Hanford Reach from June 1973 through March 1980 revealed that benthic invertebrates are important food items for nearly all juvenile and adult fish. There is a close relationship between food organisms in the stomach contents and those in the benthic and invertebrate drift communities.

Fish. Gray and Dauble (1977) list 43 species of fish in the Hanford Reach of the Columbia River. The brown bullhead (*Ictalurus nebulosus*) has been collected since 1977, bringing the total number of fish species identified in the Hanford Reach to 44 (Table 4.5-3). Of these species, chinook salmon, sockeye salmon, coho salmon, and steelhead trout use the river as a migration route to and from

Table 4.5-3. Fish species in the Hanford Reach of the Columbia River.

Common Name	Scientific Name
American shad	*Alosa sapidissima*
Black bullhead	*Ictalurus melas*
Black crappie	*Pomoxis nigromaculatus*
Bluegill	*Lepomis macrochirus*
Bridgelip sucker	*Catostomus columbianus*
Brown bullhead	*Ictalurus nebulosus*
Burbot	*Lota lota*
Carp	*Cyprinus carpio*
Channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
Chiselmouth	*Acrocheilus alutaceus*
Coho salmon	*Oncorhynchus kisutch*
Cutthroat trout	*Oncorhynchus clarki*
Dolly Varden	*Salvelinus malma*
Lake whitefish	*Coregonus clupeaformis*
Largemouth bass	*Micropterus salmoides*
Largescale sucker	*Catostomus macrocheilus*
Leopard dace	*Rhinichthys falcatus*
Longnose dace	*Rhinichthys cataractae*
Mottled sculpin	*Cottus bairdi*
Mountain sucker	*Catostomus platyrhynchus*
Mountain whitefish	*Prosopium williamsoni*
Northern squawfish	*Ptychocheilus oregonensis*
Pacific lamprey	*Entosphenus tridentatus*
Peamouth	*Mylocheilus caurinus*
Piute sculpin	*Cottus beldingi*
Prickley sculpin	*Cottus asper*
Pumpkinseed	*Lepomis gibbosus*
Rainbow trout (steelhead)	*Oncorhynchus mykiss*
Redside shiner	*Richardsonius balteatus*
Reticulate sculpin	*Cottus perplexus*
River lamprey	*Lampetra ayresi*
Sand roller	*Percopsis transmontana*
Smallmouth bass	*Micropterus dolomieui*
Sockeye salmon	*Oncorhynchus nerka*
Speckled dace	*Rhinichthys osculus*
Tench	*Tinca tinca*
Threespine stickleback	*Gasterosteus aculeatus*
Torrent sculpin	*Cottus rotheus*
Walleye	*Stizostedion vitreum vitreum*
White crappie	*Pomoxis annularis*
White sturgeon	*Acipenser transmontanus*
Yellow perch	*Perca flavescens*
Yellow bullhead	*Ictalurus natalis*

upstream spawning areas and are of the greatest economic importance. Both fall chinook salmon and steelhead trout also spawn in the Hanford Reach. The relative contribution of upper-river bright stocks to fall chinook salmon runs in the Columbia River increased from about 24% of the total in the early 1980s, to 50 to 60% of the total by 1988 (Dauble and Watson 1990). The destruction of other mainstream Columbia spawning grounds by dams has increased the relative importance of the Hanford Reach spawning (Watson 1970, 1973).

Upper estimates of the annual average Hanford Reach steelhead spawning population based on dam counts for the years 1962 to 1971 were about 10,000 fish. The estimated annual sport catch for the period from 1963 to 1968 in the reach of the river from Ringold to the mouth of the Snake River was approximately 2700 fish (Watson 1973).

Shad, another anadromous species, may also spawn in the Hanford Reach. The upstream range of the shad has been increasing since 1956 when <10 adult shad ascended McNary Dam. Since then, the number ascending Priest Rapids Dam, immediately upstream of Hanford, has risen to many thousands each year, and young-of-the-year have been collected in the Hanford Reach. The shad is not dependent on specific current and bottom conditions required by the salmonids for spawning and has apparently found favorable conditions for reproduction throughout much of the Columbia and Snake rivers.

Other fish of importance to sport fishermen are whitefish, sturgeon, smallmouth bass, crappie, catfish, walleye, and perch. Large populations of rough fish are also present, including carp, shiners, suckers, and squawfish.

4.5.2.2 Spring Streams

Small spring streams, such as Rattlesnake and Snively springs, contain diverse biotic communities and are extremely productive (Cushing and Wolf 1984). Dense blooms of watercress occur that are not lost until one of the major flash floods occurs. Aquatic insect production is fairly high as compared with mountain streams (Gaines 1987). The macrobenthic biota varies from site to site and is related to the proximity of colonizing insects and other factors.

Rattlesnake Springs, on the western side of the Hanford Site, forms a small surface stream that flows for about 2.5 km (1.6 mi) before disappearing into the ground as a result of seepage and evapotranspiration. Base flow of this stream is about 0.01 m^3/s (0.4 ft^3/s) (Cushing and Wolf 1982). Water temperature ranges from 2° to 22°C (36° to 72°). Mean annual total alkalinities (as $CaCO_3$), nitrate nitrogen, phosphate phosphorus, and total dissolved solids are 127, 0.3, 0.18, and 217 mg/L, respectively (Cushing and Wolf 1982; Cushing et al. 1980). The sodium content of the spring water is about 7 ppm (Brown 1970). Rattlesnake Springs is of ecological importance because it provides a source of water to terrestrial animals in an otherwise arid part of the Site. Snively Springs, located farther west and at a higher elevation than Rattlesnake Springs, apparently does not contribute to the flow of Rattlesnake Springs (Brown 1970), but probably flows to the west and off the Hanford Site. The major rooted aquatic plant, which in places may cover the entire width of the stream, is watercress (*Nasturtium officinal*). Isolated patches of bulrush (*Scirpus* sp.), spike rush (*Eleocharis* sp.), and cattail (*Typha latifolia*) occupy <5% of the stream bed.

Primary productivity at Rattlesnake Springs is greatest during the spring and coincident with the maximum periphyton standing crop. Net primary productivity averaged 0.9 $g/cm^2/d$ during 1969 and

1970; the spring maximum was 2.2 g/cm^2/d. Seasonal productivity and respiration rates are within the ranges reported for arid region streams. Although Rattlesnake Springs is a net exporter of organic matter during much of the growing season, it is subject to flash floods and severe scouring and denuding of the streambed during winter and early spring, making it an importer of organic materials on an annual basis (Cushing and Wolf 1984).

Secondary production is dominated by detritus-feeding collector-gatherer insects (mostly Chironomidae and Simuliidae) that have multiple cohorts and short generation times (Gaines et al. 1992). Overall production is not high and is likely related to the low diversity found in these systems related to the winter spates that scour the spring-streams. Total secondary production in Rattlesnake and Snively springs is 16,356 and 14,154 g/DWm^2/yr, respectively. There is an indication that insects in these spring-streams depend on both autochthonous and allochthonous primary production as an energy source, despite significant shading of these spring-streams that would appear to preclude significant autochthonous production (Mize 1993).

An inventory of the many springs occurring on the Rattlesnake Hills has been published by Schwab et al. (1979). Limited physical and chemical data are included for each site.

4.5.2.3 Wetlands

Several habitats on the Hanford Site could be considered wetlands. The largest wetland habitat is the riparian zone bordering the Columbia River. The extent of this zone varies but includes extensive stands of willows, grasses, various aquatic macrophytes, and other plants. The zone is extensively impacted by both seasonal water-level fluctuations and daily variations related to power generation at Priest Rapids Dam immediately upstream of the Site.

Other extensive areas of wetlands can be found within the Saddle Mountain National Wildlife Refuge and the Wahluke Wildlife Area; these two areas encompass all the lands extending from the north bank of the Columbia River northward to the Site boundary and east of the Columbia River down to Ringold Springs. Wetland habitat in these areas consists of fairly large pond habitat resulting from irrigation runoff (see Figure 4.3-1). These ponds have extensive stands of cattails (*Typha* sp.) and other emergent aquatic vegetation surrounding the open-water regions. They are extensively used as resting sites by waterfowl.

Some wetlands habitat exists in the riparian zones of some of the larger spring streams on the ALE Reserve of the Hanford Site (see earlier description). These are not extensive and usually amount to less than a hectare in size, although the riparian zone along Rattlesnake Springs is probably about 2 km (1.2 mi) in length and consists of peachleaf willows, cattails, and other plants.

The U.S. Fish and Wildlife Service has published a series of 1:24,000 maps that show the locations of wetlands. An accompanying booklet describes how to use these maps. Four sets of these maps, covering the Hanford Site, and the instructional booklet for their use are available. They are located at 1) the office of D. A. Neitzel, Sigma 5 Building/Room 2216 (Pacific Northwest Laboratory); 2) the Technical Library, Pacific Northwest Laboratory; 3) the office of the Richland Office NEPA Compliance Officer; and 4) the environmental restoration contractor.

4.5.2.4 Temporary Water Bodies

The temporary wastewater ponds and ditches have been in place for as long as two decades, although many have been eliminated. Rickard et al. (1981) discussed the ecology of Gable Mountain Pond, one of the former major lentic sites. Emery and McShane (1980) presented ecological characteristics of all the temporary sites. The ponds develop luxuriant riparian communities and become quite attractive to autumn and spring migrating birds; several species nest near the ponds. Section 4.3.1.7 describes those sites still active.

4.5.3 Threatened and Endangered Species

Threatened and endangered plants and animals identified on the Hanford Site, as listed by the federal government (50 CFR 17) and Washington State (Washington Natural Heritage Program 1994), are shown in Table 4.5-4. No plants or mammals on the federal list of endangered and threatened wildlife and plants (50 CFR 17) are known to occur on the Hanford Site. There are, however, three species of birds on the federal list of threatened and endangered species and several species of both plants and animals that are under consideration for formal listing by the federal government and Washington State.

The shrub-steppe habitat is considered priority habitat by Washington because of its relative scarcity in the state, and because of its requirement as nesting/breeding habitat by several state and federal species of concern. Several recent publications describing the distribution of threatened and endangered species on the Hanford Site have been prepared by Becker (1993), Cadwell (1994), Downs et al. (1993), Fitzner et al. (1994), and Frest and Johannes (1993).

4.5.3.1 Plants

Five species of plants are included in the Washington State listing (Washington Natural Heritage Program 1994): Columbia milk-vetch (*Astragalus columbianus*), Dwarf evening primrose (*Oenothera pygmaea*), and Hoover's desert parsley (*Lomatium tuberosum*) are listed as threatened; Columbia yellowcress (*Rorippa columbiae*) and northern wormword (*Artemisia campestris* ssp. *borealis* var. *wormskioldii*) are designated endangered. Columbia milk-vetch occurs on dry-land benches along the Columbia River near Priest Rapids Dam, Midway, and Vernita; it also has been found atop Umtanum Ridge and in Cold Creek Valley near the present vineyards. Dwarf evening primrose has been found on mechanically disturbed areas (i.e., the gravel pit near the Wye Barricade). Hoover's desert parsley grows on steep talus slopes near Priest Rapids Dam, Midway, and Vernita. Yellowcress occurs in the wetted zone of the water's edge along the Columbia River. Northern wormwood is known to occur near Beverly and could inhabit the northern shoreline of the Columbia River across from the 100 Areas.

4.5.3.2 Animals

The federal government lists the Aleutian Canada goose (*Branta canadensis leucopareia*) and the bald eagle (*Haliaeetus leucocephalus*) as threatened and the peregrine falcon (*Falco peregrinus*) as endangered. The state of Washington lists, in addition to the peregrine falcon, the Aleutian Canada

Table 4.5-4. Threatened (T) and endangered (E) species occurring or potentially occurring on the Hanford Site.

Common Name	Scientific Name	Federal	State
Insects			
Oregon silverspot butterfly[a]	*Speyerra zerone*	T	T
Plants			
Columbia milk-vetch	*Astragalus columbianus*		T
Columbia yellowcress	*Rorippa columbiae*		E
Dwarf evening primrose	*Oenothera pygmaea*		T
Hoover's desert parsley	*Lomatium tuberosum*		T
Northern wormwood[a]	*Artemisia campestris borealis* var. *wormskioldii*		E
Birds			
Aleutian Canada goose[b]	*Branta canadensis leucopareia*	T	E
American white pelican	*Pelecanus erythrorhychos*		E
Bald eagle	*Haliaeetus leucocephalus*	T	T
Ferruginous hawk	*Buteo regalis*		T
Peregrine falcon[b]	*Falco peregrinus*	E	E
Sandhill crane[b]	*Grus canadensis*		E
Mammals			
Pygmy rabbit[a]	*Brachylagus idahoensis*		E

(a) Likely not currently occurring on the Site.
(b) Incidental occurrence.

goose, white pelican (*Pelecanus erythrorhynchos*), and sandhill crane (*Grus canadensis*) as endangered and the ferruginous hawk (*Buteo regalis*) and the bald eagle as threatened. The peregrine falcon is a casual migrant to the Hanford Site and does not nest here. The bald eagle is a regular winter resident and forages on dead salmon and waterfowl along the Columbia River; it does not nest on the Hanford Site, although it has attempted to for the past several years. Access controls are in place along the river at certain times of the year to prevent the disturbance of eagles. Washington State Bald Eagle Protection Rules were issued in 1986 (WAC-232-12-292). DOE has prepared a site management plan (Fitzner and Weiss 1994) to mitigate eagle disturbance in response to the rules. This document constitutes a biological assessment for those activities implemented in accordance with the plan and, unless there are extenuating circumstances associated with a given project, the document fulfills the requirements of Section 7(a)(2) of the Endangered Species Act of 1973 for bald eagles and peregrine falcons. The Endangered Species Act of 1973 will also require Section 7 consultation when any action is taken that may destroy, adversely modify, or jeopardize the existence of bald eagle or other endangered species' habitat. An increased use of power poles for nesting sites by the ferruginous hawk on the Hanford Site has been noted.

Table 4.5-5 lists the designated candidate species under consideration for possible addition to the threatened or endangered list.

Table 4.5-6 lists Washington State plant species that are of concern and are currently listed as sensitive or are in one of three monitor groups (Washington Natural Heritage Program 1994).

4.5.4 Special Ecological Considerations in the 100 Areas

In the 100 Areas, cheatgrass is prevalent because of the extensive perturbation of soils in these areas. The characteristic communities found are cheatgrass-tumble mustard, sagebrush/cheatgrass, or Sandberg's bluegrass, sagebrush-bitterbrush/cheatgrass, and willow-riparian vegetation near the Columbia River shoreline. California quail and Chinese ring-necked pheasants are more likely to be found near the Columbia River, and several mammals, such as raccoons, beavers, and porcupines, are more likely to be present near water.

4.6 Cultural, Archaeological, and Historical Resources

With construction of dams elsewhere in the Columbia River system, the Hanford Reach is one of the most archaeologically rich areas in the western Columbia Plateau. It contains numerous well-preserved archaeological sites representing prehistoric, historic, and contact periods and is still thought of as a homeland by many Native American people. Historic period resources include sites, buildings, and structures from the pre-Hanford Site, Manhattan Project, and Cold War eras. Sitewide management of Hanford's cultural resources follows the Hanford Cultural Resources Management Plan (Chatters 1989).

There are currently 645 cultural resource sites and isolated finds recorded in the files of the Hanford Cultural Resources Laboratory (HCRL). Forty-eight archaeological sites and one building are included on the National Register of Historic Places (National Register): one reactor building, three single archaeological sites, and 45 in seven archaeological districts (Table 4.6-1). National Register nominations have been prepared for several archaeological districts and sites considered to be eligible for listing on the National Register. National Register nominations for the Gable Mountain/Gable Butte Cultural District, the Wahluke Archaeological District, and Coyote Rapids Archaeological District were submitted to the State Historic Preservation Office (SHPO) for review and comment in the 1970s. None were approved for submittal to the Keeper of the National Register. The SHPO did, however, list each district on the State Register of Historic Places (State Register). All three are pending renomination to the National Register. A fourth National Register nomination for the Hanford South Archaeological District, submitted to SHPO in 1983, is also pending renomination (Table 4.6-2). SHPO recently concurred that four sites (45BN163, 45BN423, 45BN434, and 45BN446) are eligible for listing on the National Register and that a fifth, 3-17, is not.

Table 4.5-5. Candidate species to the threatened or endangered list.

Common Name	Scientific Name	Federal[a]	State
Molluscs			
Columbia pebble snail	*Fluminicola (= Lithoglyphus)* columbiana	X(C2)	X
Shortfaced lanx	*Fisherola (= Lanx) nuttalli*	X(C3)	X
Birds			
Black tern[b]	*Chlidonius niger*	X(C2)	
Burrowing owl	*Athene cunicularia*		X
Common loon	*Gavia immer*		X
Ferruginous hawk	*Buteo regalis*	X(C2)	
Flammulated owl[b]	*Otus flammeolus*		X
Golden eagle	*Aquila chrysaetos*		X
Lewis' woodpecker[b]	*Melanerpes lewis*		X
Loggerhead shrike	*Lanius ludovicianus*	X(C2)	X
Long-billed curlew	*Numenius americanus*	X(C3)	
Northern goshawk[b]	*Accipter gentilis*	X(C2)	X
Sage sparrow	*Amphispiza belli*		X
Sage thrasher	*Oreoscoptes montanus*		X
Swainson's hawk	*Buteo swainsoni*		X
Trumpeter swan[b]	*Cygnus columbianus*	X(C2)	
Western bluebird[b]	*Sialia mexicana*		X
Western sage grouse[b]	*Centrocercus urophasianus phaios*	X(C2)	X
Insects			
Columbia River tiger beetle[c]	*Cinindela colubica*		X
Reptiles			
Striped whipsnake	*Masticophis taeniatus*		X
Mammals			
Merriam's shrew	*Sorex merriami*		X
Pacific western big-eared bat[c]	*Plecotus townsendii townsendii*	X(C2)	X
Pygmy rabbit[c]	*Brachylagus idahoensis*	X(C2)	

Table 4.5-5. (Cont'd)

Common Name	Scientific Name	Federal[a]	State
Plants			
Columbia milk-vetch	*Astragalus columbianus*	X[(C1)]	
Columbia yellowcress	*Rorippa columbiae*	X[(C2)]	
Hoover's desert parsley	*Lomatium tuberosum*	X[(C2)]	
Northern wormwood[c]	*Artemisia campestris borealis* var. *wormskioldii*	X[(C1)]	

(a) Abbreviations:
C1 = Taxa for which the U.S. Fish and Wildlife Service has enough substantial information on biological vulnerability to support proposals to list them as endangered or threatened species. Listing is anticipated but has temporarily been precluded by other listing activity.
C2 = Taxa for which current information indicates that proposing to list as endangered or threatened is possibly appropriate, but for which conclusive data on biological vulnerability are not available to support listing. The U.S. Fish and Wildlife Service will not propose listing unless additional supporting information becomes available.
C3 = Taxa that were once considered for listing as endangered or threatened (i.e., in categories 1 or 2) but are no longer current candidates for listing. Such taxa are further subdivided into three categories that indicate why they were removed from consideration.
(b) Reported, but seldom observed, on the Hanford Site.
(c) Probable, but not observed, on the Hanford Site.

There are approximately 1000 to 1500 buildings and structures on the Hanford Site. This figure does not include mobile trailers, modular buildings, and subsurface facilities and utilities such as cribs, trenches, sewers, communication lines, and fuel and waste storage tanks. Of the 1000 to 1500 buildings/structures, approximately 245 have been inventoried and recorded on Washington State Historic Property Inventory Forms, now located in HCRL files. While only one building/structure, 105-B (B Reactor), is listed on the National Register of Historic Places, approximately 43 other buildings have been evaluated for National Register eligibility (Table 4.6-3). The SHPO has also recognized the potential of National Register historic districts in the 200 and 300 Areas.

Cultural resource reviews are conducted before Hanford Site projects that entail disturbing ground and/or altering or demolishing existing structures are begun. About 100 to 120 reviews were conducted annually through 1991, and this figure rose to more than 500 reviews during 1994. These reviews ensure that prehistoric and historic sites and existing structures eligible for the National Register are not adversely impacted by proposed projects.

A cultural resource review begins with a literature and records search of HCRL files. For excavation projects, if a proposed project area is found to be undisturbed and has not been surveyed, a pedestrian survey is conducted. If a site is encountered, found to be eligible, but cannot be avoided, mitigation of project impacts will be necessary. If no sites are found on the surface but the project area is known to be in a culturally sensitive location, archaeologists may monitor the construction for

Table 4.5-6. Washington State plant species of concern occurring on the Hanford Site.

Common Name	Scientific Name	Status[a]
Bristly cryptantha	*Cryptantha interrupta*	M2
Columbia River mugwort	*Artemisia lindleyana*	M3
Crouching milkvetch	*Astragalus succumbens*	M3
Dense sedge	*Carex densa*	S
Desert evening primrose	*Oenothera cespitosa*	S
False pimpernel	*Lindernia anagallidea*	S
Fuzzy-beard tongue penstemon	*Penstemon eriantherus*	M3
Gray cryptantha	*Cryptantha leucophaea*	S
Medic milkvetch	*Astragalus speirocarpus*	M3
Palouse thistle	*Cirsium brevifolium*	M3
Piper's daisy	*Erigeron piperianus*	S
Robinson's onion	*Allium robinsonii*	M3
Rosy balsamroot	*Balsamorhiza rosea*	M3
Shining flatsedge	*Cyperus rivularis*	S
Smooth cliffbrake	*Pellaea glabella*	M3
Southern mudwort	*Limosella acaulis*	S
Squill onion	*Allium scillioides*	M3
Stalked-pod milkvetch	*Astragalus sclerocarpus*	M3
Thompson's sandwort	*Arenaria franklinii* v. *thompsonii*	M2
Tooth-sepal dodder	*Cuscuta denticulata*	M1

The following species may inhabit the Hanford Site, but have not been recently collected, and the known collections are questionable in terms of location and/or identification.

Coyote tobacco	*Nicotiana attenuata*	S
Few-flowered blue-eyed Mary	*Collinsia sparsiflora*	S
Palouse milkvetch	*Astragalus arrectus*	S

(a) Abbreviations:
- S = sensitive, i.e., taxa vulnerable or declining, and could become endangered or threatened without active management or removal of threats;
- M1 = Monitor group 1. Taxa for which there are insufficient data to support listing as threatened, endangered, or sensitive.
- M2 = Monitor group 2, i.e., taxa with unresolved taxonomic questions.
- M3 = Monitor group 3, i.e., taxa that are more abundant and/or less threatened than previously assumed.

Table 4.6-1. Historic properties on the Hanford Site listed on the National Register of Historic Places and the archaeological sites within them.

Property Name	Site(s) Included
Hanford Island Archaeological Site[a]	45BN121
Hanford North A.D.	45BN124 through 45BN134, 45BN178
Locke Island A.D.	45BN137 through 45BN140, 45BN176, 45GR302a, 45GR302b, 45GR302c, 45GR303 through 45GR305
Paris Archaeological Site	45GR317
Rattlesnake Springs Sites	45BN170 and 45BN171
Ryegrass A.D.	45BN149 through 45BN151
Savage Island A.D.	45BN116 through 45BN119, 45FR257 through 45FR262
Snively Canyon A.D.	45BN172 and 45BN173
Wooded Island A.D.	45BN107 through 45BN112
105-B Reactor	N/A[b]

(a) A.D. indicates archaeological district (this table).
(b) N/A = not applicable.

Table 4.6-2. Historic properties on the Hanford Site nominated, or prepared for nomination, to the National Register of Historic Places.

Property Name[a]	Site(s) Included
Coyote Rapids A.D.[b,c]	45BN152, 45GR312 through 45GR314
Gable Mountain/Gable Butte Archaeological Site[a,b,c]	45BN348 through 45BN363, 45BN402 through 45BN410
Hanford South A.D.[c,d]	45BN026 through 45BN036; 45BN040 through 45BN045; 45BN101 through 45BNN112; 45BN162 through 45BN168; 45BN191, 45BN192; 45FR019 through 45FR025; 45FR251 through 45FR253, and 45FR308
Wahluke A.D.[b,c]	45BN141 through 45BN148; 45GR306A, 45GR306B, 45GR307C

(a) Nomination forms have been prepared. A.D. = archaeological district (this table).
(b) Nominated; rejected because of lack of documentation; renomination is pending.
(c) Archaeological District is listed on the Washington State Register of Historic Places.
(d) Nominated; rejected because of technical issues and unresolved questions involving ownership of lands included in the nomination.

Table 4.6-3. Buildings and structures evaluated for National Register eligibility.

Building No.	Building Function	National Register Eligibility
100 Areas		
105-B	Nuclear Reactor	Listed
183-C	Filter Building	No
190-C	Main Pump House	No
185-D	Development Lab	Yes
189-D	Development Lab	Yes
190-D	Tank Room/Pumphouse	Yes[a]
190-DA	Process Pump Annex	Yes[a]
195-D	Vertical Safety Rod Test Tower	Yes[a]
1724-D	Underwater Testing Facility	Yes[a]
1713-H	Warehouse	No
104-N	Facilities Auxiliary Shop	No
105-NA	Emergency Diesel Bldg	No
105-NB	Mechanical Shop Addition	No
105-NC	Emergency Diesel Generator Bldg	No
109-NA	Steam/Flow Instrument Bldg	No
109-NB	Hydro Power Unit Bldg	No
1112-NB	Temporary Badge House	No
1707-N	Patrol Boat House	No
1734-N	Gas Bottle Storage Bldg	No
200 West Area		
232-Z	Waste Incinerator Facility	Yes
233-S	Plutonium Concentration Bldg	Yes[b]
2719-WA	First Aid Facility	No
200 East Area		
None		
300 Area		
313	Fuel Manufacturing/Metal Fab.	Yes[b]
331	Life Sciences Bldg	No
3703	Offices	No
3745-A	Electron Accelerator Lab	Yes[b]
3745-B	Positive Ion Lab	Yes[b]

Table 4.6-3. (Cont'd)

Building No.	Building Function	National Register Eligibility
400, 600, 700, 1100 Areas		
None		
3000 Area		
1154	Telecommunications Shop	Yes
.1208	Paint Shop	No
1209	X Ray Facility	No
1211	Sand Blast Facility	No
1226	Auto Shop	No
1227	Equipment Storage	No
1235	Bottled Gas Storage	No
1240	Fabrication Shop	No
1241	Plate Shop	No
1242	Compressor Bldg	No
1252	Warehouse	No
1253	Combustible Materials Storage	No
1256	Office	No
1262	Office	No
1264	Office	No
1301	Office	No

(a) Not individually eligible but significant because of association with adjoining buildings eligible for the National Register.

(b) Not individually eligible but a contributing element to a potential National Register historic district.

subsurface archaeological materials. Projects could be halted until site mitigation has been completed if archaeological materials are discovered during construction activities. If human remains are inadvertently discovered during construction, all work must cease as required by the Native American Graves Repatriation and Protection Act. If significant building alterations and demolitions are proposed, the building is recorded on a historic property inventory form, which includes a description of physical appearance, a statement of historical significance, and photographic documentation. Determinations of potential eligibility for cultural resource sites and buildings are submitted to the SHPO for concurrence. If the archaeological site, traditional cultural property, building, or structure is found to be eligible, a more extensive method of documentation or data recovery may be used as a form of mitigation if adverse impacts cannot be avoided.

4.6.1 Native American Cultural Resources

In prehistoric and early historic times, the Hanford Reach of the Columbia River was populated by Native Americans of various tribal affiliations. The Wanapum and the Chamnapum band of the Yakama tribe dwelt along the Columbia River from south of Richland upstream to Vantage (Relander 1956; Spier 1936). Some of their descendants still live nearby at Priest Rapids (the Wanapum Tribe), others have been incorporated into the Yakama and Umatilla reservations. Palus people, who lived on the lower Snake River, joined the Wanapum and Chamnapum to fish the Hanford Reach of the Columbia River and some inhabited the river's east bank (Relander 1956; Trafzer and Scheuerman 1986). Walla Walla and Umatilla people also made periodic visits to fish in the area. Descendants of these people retain traditional secular and religious ties to the region, and many, young and old alike, have knowledge of the ceremonies and lifeways of their ancestral culture.

The *Washani* religion, which has ancient roots and had its start on the Hanford Site, is still practiced by many people on the Yakama, Umatilla, Warm Springs, and Nez Perce reservations. Native plant and animal foods, some of which can be found on the Hanford Site, are used in the ceremonies performed by tribal members. Tribes have expressed an interest in renewing their use of these resources, and the DOE is assisting them in this effort. Certain landmarks, especially Rattlesnake Mountain, Gable Mountain, Gable Butte, Goose Egg Hill, and various sites along and including the Columbia River, are sacred to them.

4.6.2 Archaeological Resources

People have inhabited the Middle Columbia River region since the end of the glacial period. More than 10,000 years of prehistoric human activity in this largely arid environment have left extensive archaeological deposits along the river shores (Chatters 1989; Greengo 1982; Leonhardy and Rice 1970). Well-watered areas inland from the river also show evidence of concentrated human activity (Chatters 1982, 1989; Daugherty 1952; Greene 1975; Leonhardy and Rice 1970; Rice 1980), and recent surveys have indicated extensive, although dispersed, use of arid lowlands for hunting. Graves are common in various settings, and spirit quest monuments are still found on high, rocky summits of the mountains and buttes (Rice 1968a). Throughout most of the region, hydroelectric development, agricultural activities, and domestic and industrial construction have destroyed or covered the majority of these deposits. Amateur artifact collectors have had an immeasurable impact on what remains. By virtue of their inclusion in the Hanford Site from which the public is restricted, archaeological deposits found in the Hanford Reach of the Columbia River and on adjacent plateaus and mountains have been spared some of the disturbances that have befallen other sites. The Hanford Site is thus a *de facto* reserve of archaeological information of the kind and quality that have been lost elsewhere in the region.

Two hundred and eighty-three prehistoric sites have been found on Hanford, 17 of which contain prehistoric and historic components. Prehistoric archaeological sites common to the Hanford Site include remains of numerous pit house villages, various types of open campsites, cemeteries, spirit quest monuments (rock cairns), hunting camps, game drive complexes, and quarries in mountains and rocky bluffs (Rice 1968a, 1968b, 1980); hunting/kill sites in lowland stabilized dunes; and small temporary camps near perennial sources of water located away from the river (Rice 1968b).

Many recorded sites were found during four archaeological reconnaissance projects conducted between 1926 and 1968 (Drucker 1948; Krieger 1928; Rice 1968a, 1968b). Much of this early archaeological survey and reconnaissance activity concentrated on islands and on a strip of land approximately 400 m (1312 ft) wide on either side of the river (Rice 1980). Reconnaissance of several project-specific areas and other selected locations conducted through the mid-1980s added to the recorded site inventories. Systematic archaeological surveys conducted from the middle 1980s through 1994 are responsible for much of the remainder (Chatters 1989; Chatters and Cadoret 1990; Chatters and Gard 1992; Chatters et al. 1990, 1991, 1992; Last et al. 1993).

The Mid-Columbia Archaeological Society (MCAS) conducted minor test excavations at several sites on the river banks and islands (Rice 1980) and a larger scale test at site 45BN157 (Den Beste and Den Beste 1976). The University of Idaho also excavated a portion of site 45BN179 (Rice 1980) and collaborated with the MCAS on its other work. Test excavations were conducted at other sites to determine National Register eligibility (Table 4.6-4).

Table 4.6-4. Test excavations conducted on the Hanford Site.

Property Name	Excavation Conducted By
45BN090	Western Washington University, Hanford Cultural Resources Laboratory
45BN149	Mid-Columbia Archaeological Society
45BN157A	Mid-Columbia Archaeological Society, University of Idaho, Columbia Basin College
45BN163 and 45BN164	Hanford Cultural Resources Laboratory
45BN179 and 45BN180	University of Idaho
45BN257	Rice
45BN307	ERTEC, Northwest Inc.
45BN423	Hanford Cultural Resources Laboratory
45BN432 and 45BN433	Hanford Cultural Resources Laboratory
45BN447	Hanford Cultural Resources Laboratory
45FR266h	University of Idaho
45GR302A	Mid-Columbia Archaeological Society
45GR306	Central Washington University, Hanford Cultural Resources Laboratory
45GR306B	Mid-Columbia Archaeological Society
45GR317	Mid-Columbia Archaeological Society
45GR318	Mid-Columbia Archaeological Society

During his reconnaissance of the Hanford Site in 1968, Rice (1968b) inspected portions of Gable Mountain, Gable Butte, Snively Canyon, Rattlesnake Mountain, and Rattlesnake Springs. Rice also inspected additional portions of Gable Mountain and part of Gable Butte in the late 1980s (Rice 1987). Some reconnaissance of the Basalt Waste Isolation Project Reference Repository Location (Rice 1984), a proposed land exchange in T. 22 N., R. 27 E., Section 33 (Rice 1981), and three narrow transportation and utility corridors (ERTEC 1982; Morgan 1981; Smith et al. 1977) were also conducted. Other large-scale proposed project areas have been completed in recent years, including the 100 Areas from 1991 through 1993 (Chatters et al. 1992; Wright 1993), McGee Ranch (Gard and Poet 1992), the Laser Interferometer Gravitational Wave Observatory Project, the North Slope Waste Sites Project, and the Environmental Restoration Disposal Facility. To date, approximately 6% of the Hanford Site has been surveyed.

4.6.3 Historic Archaeological Resources

The first Euroamericans who came into this region were Lewis and Clark, who traveled along the Columbia and Snake rivers during their 1803 to 1806 exploration of the Louisiana Territory. They were followed by fur trappers, military units, and miners who passed through on their way to more productive lands up and down river passageways and across the Columbia Basin. It was not until the 1860s that merchants set up stores, a freight depot, and the White Bluffs Ferry on the Hanford Reach. Chinese miners began to work the gravel bars for gold. Cattle ranches were established in the 1880s, and farmers soon followed. Several small, thriving towns, including Hanford, White Bluffs, and Ringold, grew up along the riverbanks in the early twentieth century. Other ferries were established at Wahluke and Richmond. The towns and nearly all other structures were razed after the U.S. Government acquired the land for the Hanford Engineer Works in 1943 (Chatters 1989; ERTEC 1981; Rice 1980).

A total of 201 historic archaeological sites and numerous historic properties have been recorded, which are associated with the pre-Hanford Site era. Properties from the pre-Hanford Site era include semi-subterranean structures near McGee Ranch; the Hanford Irrigation and Power Company's pumping plant at Coyote Rapids; the Hanford Irrigation Ditch; the old Hanford Townsite, pumping plant, and high school; Wahluke Ferry; the White Bluffs Townsite and bank; the Richmond Ferry; Arrowsmith Townsite; a cabin at East White Bluffs ferry landing; the White Bluffs road; the Chicago, Milwaukee, St. Paul, and Pacific Railroad (Priest Rapids-Hanford Line) and associated whistle stops; and Bruggeman's fruit warehouse (Rice 1980). Historic archaeological sites, including an assortment of farmsteads, corrals, and dumps, have been recorded by the HCRL since 1987. ERTEC Northwest was responsible for minor test excavations at some of the historic sites, including the old Hanford Townsite (Table 4.6-4). Resources from the pre-Hanford Site period are scattered over the entire Hanford Site and include numerous areas of gold mine tailings along riverbanks of the Columbia and the remains of homesteads, agricultural fields, ranches, and irrigation-related features.

4.6.4 Historic Architectural Resources

Historic architectural resources documented from the Manhattan Project and Cold War eras include buildings and structures primarily found in the 100, 200, and 300 Areas. The most important of these are the defense reactors and plutonium-production and processing facilities. The first reactors (100-B, 100-D, and 100-F) were constructed in 1943 as part of the Manhattan Project. Plutonium for the first atomic explosion and the bomb that destroyed Nagasaki to end World War II were produced in the 100-B Facility. Additional reactors and processing facilities were constructed after World War II, within the Cold War period. All reactor containment buildings still stand, although many ancillary structures have been removed. Table 4.6-3 lists the buildings/structures that have been evaluated for National Register eligibility by the SHPO.

Remaining buildings and facilities in the 100 Areas and 300/3000 Areas will be inventoried during FY 1995 with National Register evaluations planned for completion during FY 1996. In the interim, individual buildings scheduled for major remodeling or demolition are evaluated on an as-needed basis through the end of FY 1995. Long-range plans for site-wide building evaluations include the use of prepared historic contexts for the Manhattan Project and Cold War eras to assist with National Register eligibility determinations.

4.6.5 100 Areas

Intensive field surveys were completed in the 100 Areas from 1991 to 1993. Much of the surface area within the 100 Area Operable Units has been disturbed by the industrial activities that have taken place during the past 50 years. However, numerous prehistoric and historic archaeological sites have been encountered, and many are potentially eligible for the National Register. A complete inventory of historic period 100 Area buildings and structures will be completed during FY 1995, and a National Register evaluation for each will be finalized during 1996. To date, approximately 23 buildings/structures have been inventoried in the 100 Areas. See Table 4.6-3 for National Register eligibility status of evaluated properties.

100-B/C Area. Three sites can be identified from area literature (Rice 1968a, 1980); all lie partially within the 100-B/C Area. The remains of Haven Station, a small stop on the old Chicago, Milwaukee, and Saint Paul railroad, is located to the west of the reactor compound. A fourth archaeological site and the remains of the small community of Haven lie on the opposite bank of the Columbia River. Many sites related to hunting and religious activities are located at the west end of Gable Butte, due south of the 100 B/C Area. These sites are part of the proposed Gable Mountain/Gable Butte Cultural District nomination.

Two sites located in the general area near 100 B/C have been investigated. Test excavations conducted in 1991 at one hunting site revealed large quantities of deer and mountain sheep bone and projectile points dating from 500 to 1500 years old. A second archaeological site, 45BN466 is considered to be eligible for listing on the National Register, in part, because it may contain new information about the Frenchman Springs and Cayuse Phases of prehistory.

B Reactor was the first full-scale plutonium production reactor and is designated as a National Historic Mechanical Engineering Landmark. It is also listed on the National Register, was recently named as a National Civil Engineering Landmark, and was given the Nuclear Historic Landmark Award. Several buildings from the Manhattan Project and early Cold War eras remain standing within the reactor compound, including 183-C and 190-C, which have been determined to be ineligible for the National Register. The other buildings will be inventoried in 1995 and evaluated for National Register eligibility in 1996.

100-D Area. Sixty-six known archaeological sites lie within 2 km (1.2 mi) of the 100-D/DR reactor compound, three on the northern bank and sixty-three on the southern bank. Sites 45BN147 and 45BN148 located north of the reactor compound are within the Wahluke Archaeological District. Ten sites located south of the reactor compound may be potentially eligible for the National Register because of their association with a traditional cultural property. Most of the remaining sites represent early Euroamerican settlement activities. The former community of Wahluke, which was at the landing of a ferry of the same name, is also situated on the river's north bank. The mid-channel island off the 100-D Area may be the one called *Watklimpt* by the Wanapum Tribe (Relander 1956).

All of the buildings and structures in this area were built during the Manhattan Project and Cold War eras. The 185/189 buildings and adjoining facilities, all part of the 190-D complex, have been determined eligible for the National Register and have been the subject of documentation to mitigate their proposed demolition. Only one building (190-DA) in the 190-D complex has been demolished. All remaining buildings will be demolished by September 30, 1995. The other buildings/structures in this area will be inventoried in 1995 and evaluated for National Register eligibility in 1996.

100-F Area. The 100-F Area is situated on a segment of the Columbia River that contains many cultural sites. According to Relander (1956), camps and villages of the Wanapum people extended from the old Hanford Townsite upstream to the former White Bluffs Townsite. Among those were the villages of *Wakwaltkh*, *Tohoke*, and *Tacht* and the sites of *Wyone* and *Y'yownow*, which were fishing and fish processing locations, respectively. *Tacht* (the name for White Bluffs) was one of the village sites used by the Wanapum.

Four prehistoric archaeological sites, including one dating to 4000 to 9000 years old, were found in the 100-F Area during 1991 surveys. Two of these sites (45BN432 and 45BN433) are considered to be ineligible for the National Register; two have not been evaluated (45BN431 and 45BN435). During 1991 surveys, four historic sites (3-11, 3-12, 3-13, and 3-14), consisting of household debris, were found inside the 100-F Area.

There are six other prehistoric archaeological sites within 2 km (1.2 mi) of this area. They are all identified as open camps, except for one, which contains housepits. Sites of particular importance include 45BN128 (a cemetery), 45BN178 (included in the Hanford North Archaeological District and listed on the National Register of Historic Places), and 45FR264 (which appears to contain artifact deposits dating to at least 6000 years before present).

The principal historic site in the vicinity is the East White Bluffs ferry landing and former townsite, 45FR314h, which has been considered for nomination to the National Register of Historic Places. It is located on the east bank of the Columbia River and is coterminous with 45FR266. The site was the upriver terminus of shipping during the early- and mid-19th century. It was at this point that supplies for trappers, traders, and miners were off-loaded, and commodities from the interior were transferred from pack trains and wagons to river boats. The first store and ferry of the mid-Columbia region were located there (ERTEC 1981). A log cabin, thought by some to have been a blacksmith shop in the mid-19th century, still stands there. Test excavations were conducted at the cabin by the University of Idaho. The structure has been recorded according to standards of the Historic American Buildings Survey (Rice 1976). The only remaining structure associated with the White Bluffs Townsite (near the railroad) is the White Bluffs Bank. A revised historic property inventory form for the bank will be completed in 1995. Two Manhattan Project buildings, 108-F and 105-F, remain in the 100-F Area. Both will be inventoried and evaluated during 1995 and 1996.

100-H Area. There are 10 recorded archaeological sites within 2 km (1.2 mi) of the area, including 45BN138 through 45BN141, and 45GR302 (a, b, c,) through 45GR305. These include two historic Wanapum cemeteries, six camps (one with an associated cemetery), and three housepit villages. The largest village, 45GR302a, contains more than 100 housepits and numerous storage caches. It appears to have been occupied from 2500 years ago to historic times (Rice 1968a). All these sites are included in the Locke Island Archaeological District. Locke Island itself was known to the Wanapum Indians an *K'watch* (Relanders 1956). The historic village of *Tacht* was located 1 km (0.6 mi) south of the reactor facility. Several living members of the Wanapum, Palus, and Yakama tribes recall residing there. Surveys conducted in 1992 by the HCRL showed that this site had been destroyed by soil borrowing, probably in the 1940s or 1950s.

Fourteen historic sites in the vicinity were recorded during 1992 and 1993 and include 20th century farmsteads, household dumps, and military encampments. None have yet been evaluated for eligibility to the National Register of Historic Places.

Only three buildings associated with the Cold War era remain in this area (see Table 4.6-3 for eligibility status of the 1713-H Building). This and the other two buildings will be inventoried in 1995 and evaluated in 1996.

100-K Area. Events took place at this locality that were of great significance to Native American people in the interior Northwest. It was here, in the mid-19th century, that Smohalla, Prophet of the Wanapum people, held the first *Washat*, the dance ceremony that has become central to the Seven Drums or Dreamer religion (Relander 1956). As a result of Smohalla's personal abilities, the religion spread to many neighboring tribes and is now practiced in some form by members of the Colville, Nez Perce, Umatilla, Wanapum, Warm Springs, and Yakama tribes. The site of this historic event was the south bank of the Columbia River near *Moon*, or Water Swirl Place, which is also known as Coyote Rapids.

An archaeological survey of the 100-K Area in 1991 revealed five previously unrecorded archaeological sites. Two sites date to the Cascade Phase (9000 to 4000 years ago). A large fish processing camp, represented by fire-broken rock mingled with river gravel, extends downstream from Coyote Rapids. These areas have yet to be evaluated. More importantly, a recent (one or two centuries old) group of pithouses with associated long house and sweat lodge were identified and may have been the site of Smohalla's first *Washat* dance. Three other sites, 45GR312, 45GR313, and 45GR314, which compose the Coyote Rapids Archaeological District, are on the opposite bank of the river. This district was nominated to the National Register of Historic Places, but the nomination was rejected in 1976 because of insufficient information. Site 45BN151 is an historic Wanapum cemetery that was probably associated with 45BN423. The Ryegrass Archaeological District extends north and east of the 100-K reactor compound. Three archaeological sites are included: 45BN149, 45BN150, and 45BN151. All are listed on the National Register. Two other sites (45BN423 and 45BN434) have been determined by SHPO to be eligible for listing on the National Register.

Historic sites containing the remains of farms litter the nearby area; four historic sites and three isolated finds have been recorded as of 1994.

Two important linear features, the Hanford Irrigation Ditch and the former Chicago, Milwaukee, and St. Paul railroad, are also present in the 100-K Area. Remnants of the Allard community and the Allard Pumphouse at Coyote Rapids are located west of the K Reactor compound. Site forms for these historic resources will be completed in 1995.

100-N Area. Within 2 km (1.2 mi) of the 100-N Area perimeter are fourteen archaeological sites, including 45BN149, 45BN150, 45BN151, 45BN179, and 45BN180 on the south shore and 45GR309, 45GR310, and 45GR311 on the north shore. Four of these sites are either listed, or considered eligible for listing, on the National Register. Sites 45BN149, 45BN150, and 45BN151, which include two pithouse villages and one cemetery, respectively, comprise the Ryegrass Archaeological District. Site 45BN179, once considered for nomination as the Hanford Generating Plant Site, has been found to be part of 45BN149, which is already listed on the National Register (Chatters et al. 1990). Recently recorded sites include 45BN437, 45BN438, 45BN440, 45BN442, and 45BN443.

Rice (1980) conducted test excavations at 45BN179 in 1973. During that excavation, which consisted of excavating two trenches and two smaller pits, Rice found evidence of habitation during four periods of prehistory. The earliest undated occupation of the site occurred during the Vantage Phase of the local chronology (Nelson 1969; Swanson 1962), which dates to before 4500 years before present (BP). Small amounts of material, also undated, were attributable to the Frenchman Springs Phase (4500 to 2500 BP). Above that were dense artifact deposits and remains of pithouses dating after 1862 BP, which Rice attributed to the Cayuse Phase (2000 BP to historic times). Capping the sequence of deposits was debris left by Wanapum people during their historic occupation of the sites. No excavations have been conducted in other sites within the Ryegrass Archaeological District.

Extant knowledge about the archaeology of the 100-N Area is based largely on reconnaissance-level archaeological surveys conducted during the late 1960s to late 1970s (Rice 1968b; see also Rice 1980), which do not purport to produce complete inventories of the areas covered. Intensive surveys of surrounding areas were conducted during 1991. The Hanford Generating Plant vicinity has also been surveyed intensively for archaeological resources (Rice 1980).

Three areas near the 100-N Area are known to have been of some importance to the Wanapum. The knobs and kettles surrounding the area may have been called *Moolimooli*, which means Little Stacked Hills. Coyote Rapids, which is a short distance upstream, was called *Moon*, or Water Swirl Place. Gable Mountain (called *Nookshai* or Otter) and Gable Butte, which lie to the south of the river, are sacred mountains where youths would go on overnight vigils seeking guardian spirits (Relander 1956). No sites of religious importance are known to exist within the 100-N compound but may exist nearby.

The most common evidence of historic activities now found near the 100-N Area consists of gold mine tailings on riverbanks and historic archaeological sites where farmsteads once stood. The significance of most 100-N buildings and structures, their role in the Cold War, and their potential eligibility for listing on the National Register have not yet been determined. All of the buildings will be inventoried and evaluated in 1995.

4.6.6 200 Areas

An archaeological survey has been conducted of all undeveloped portions of the 200 East Area and a portion of the 200 West Area. The undeveloped portions of the 200 West Area that have not been surveyed are investigated on a project-by-project basis. The only evaluated historic site is the White Bluffs freight road that crosses diagonally through the 200 West Area. The road, which was formerly an Native American trail, has been in continuous use since antiquity and has played a role in Euroamerican immigration, development, agriculture, and Hanford Site operations. This property has been determined by the SHPO to be eligible for the National Register of Historic Places, although the segment that passes through the 200 West Area is considered to be a non-contributing element. A 100-m (328-ft) easement has been created to protect the road from uncontrolled disturbance. Historic period buildings from the Manhattan Project and Cold War eras that have not been evaluated for National Register eligibility are located in both the 200 East and 200 West Areas.

Approximately 20 existing buildings/structures in the 200 Areas have been inventoried (see Table 4.6-3 for National Register eligibility status of evaluated 200 Area buildings and structures). The remaining buildings and structures associated with the Manhattan Project and Cold War eras in the 200 Areas will be inventoried and evaluated in 1995 and 1996.

4.6.7 300 Area

Most of the 300 Area has been highly disturbed by industrial activities. Several archaeological surveys of the 300 Area have been conducted (Cleveland et al. 1976; Drucker 1948; Morgan 1981; Rice 1968a; Thomas 1983), as well as several smaller surveys conducted by the HCRL for specific DOE-RL projects. Five recorded sites are located at least partially within the 300 Area; however, many more may be located in subsurface deposits. The first four sites listed are prehistoric, including camp sites and housepits. One is a historic trash scatter.

Twenty-one archaeological sites and three isolated artifacts have been recorded within 2 km (1.2 mi) of the 300 Area fence. Eleven are prehistoric, nine are historic, and one contains both prehistoric and historic components. The historic sites consist of debris scatters and road beds associated with farmsteads. Areas surrounding the 300 Area have been only minimally surveyed. Regardless of this fact, historic sites have been documented and several additional historic sites may be expected in this outlying area. Site 45BN163 has been tested for subsurface deposits and is recognized as eligible for listing on the National Register. Several sites in this area, including 45BN163, are in the Hanford South Archaeological District, which is listed on the State Register.

One documented locality with great importance to the historic Wanapum Tribe is located near the 300 Area. *Sekema*, a favorite place for taking salmon that had already spawned, was located some 10 km (6 mi) north of Richland (Relander 1956) or 2 to 3 km (1.2 to 1.8 mi) north of the 300 Area boundary. However, because Relander's descriptions of geographic locations are only approximate, it is possible that *Sekema* corresponds to any or all of the sites in or around the 300 Area listed previously.

All of the approximately 154 buildings/structures in the 300 Area were constructed during the Manhattan Project and Cold War eras. These facilities were inventoried in 1995 with National Register evaluations (see Table 4.6-3 for eligibility status of evaluated 300 Area buildings and structures) to be completed in 1996.

4.6.8 400 Area

Most of the 400 Area has been so disrupted by construction activities that archaeologists surveying the site in 1978 were able to find only 30 acres that were undisturbed (Rice et al. 1978). They found no cultural resources in those 30 acres. No sites are known to be located within 2 km (1.2 mi) of the 400 Area.

All of the buildings and structures in the 400 Area were constructed during the Cold War era. None of these properties have been inventoried. Buildings will be inventoried and evaluated in 1995 and 1996.

4.6.9 600 Area

The 600 Area contains a diverse wealth of cultural resource sites and traditional cultural properties representing a full range of human activity both temporally and spatially across the Hanford Site. Project-driven surveys have been conducted throughout the area but much of the 600 Area remains unsurveyed.

Approximately 14 buildings/structures, including the Nike missile storage facility, are in the process of being inventoried at the former Nike launch center headquarters at the base of Rattlesnake Mountain in the Fitzner/Eberhardt Arid Lands Ecology (ALE) Reserve. None have been evaluated for National Register eligibility. There are plans to complete the inventory of Cold War facilities on ALE in 1995 including the former Nike control center on the ridge of Rattlesnake Mountain. Buildings will be evaluated in 1996 or when they are scheduled for major alterations or demolition.

Five anti-aircraft artillery sites, HT-94-028 to HT-94-032, located in the 600 Area have been determined eligible for the National Register by the SHPO. Because of the proposed clean-up of these sites, mitigation to reduce the adverse effects will be carried out during 1995/1996. The Central Shops complex, HT-94-027, located in the 600 Area was determined ineligible for the National Register by the SHPO in 1995.

4.6.10 700 Area

Most of the 700 Area has been highly disturbed by industrial activities. No buildings or structures have been inventoried in this area. Properties will be inventoried and evaluated when they are scheduled for major alterations or demolition.

4.6.11 1100 Area

Historic cultural resources have been identified in or near the 1100 Area. These include remains of farmsteads, homesteads, and agricultural structures predating the Hanford Site. No mention is made by Relander (1956) of any location important to the Wanapum Tribe. All of these historic sites will be evaluated for National Register eligibility before the start of proposed projects that could impact them.

4.6.12 3000 Area

Archaeological surveys of the 3000 Area have been confined to a narrow strip along the Columbia River (Cleveland et al. 1976; Drucker 1948; Rice 1968a; Thoms 1983). Twelve sites are within 2 km (1.2 mi) of the area, including 45BN26 through 45BN28, 45BN104, and 45BN267 located on the west bank; 45BN43, 45BN44, 45BN101 through 45BN103, and 45BN192 located on an island; and 45FR308 located on the east bank. Many of these sites are included in the Hanford South Archaeological District, which was nominated for listing on the National Register in 1983. The nomination was not accepted by the SHPO and has not been finalized. Site types in the 3000 Area include burials, open camp/fishing stations, shell middens, and housepit sites.

No historic sites have been recorded for this area, but homesteads and remnants of the former North Richland Townsite, Manhattan Project/early Cold War construction camp housing and buildings associated with the 1950s Camp Hanford are found there. Battelle's Operations and Service Building (OSB) was inventoried during the recent 300/3000 Area survey. All of the 3000 industrial area buildings/structures have been inventoried and evaluated (see Table 4.6-3).

4.7 Socioeconomics

Activity on the Hanford Site plays a dominant role in the socioeconomics of the Tri-Cities (Richland, Pasco, and Kennewick) and other parts of Benton and Franklin counties. The agricultural community also has a significant effect on the local economy. Any major changes in Hanford activity would potentially affect the Tri-Cities and other areas of Benton and Franklin counties.

4.7.1 Employment and Income

Three major sectors have been the principal driving forces of the economy in the Tri-Cities since the early 1970s: 1) DOE and its contractors operating the Hanford Site; 2) Washington Public Power Supply System in its construction and operation of nuclear power plants; and 3) the agricultural community, including a substantial food-processing component. With the exception of a minor amount of agricultural commodities sold to local-area consumers, the goods and services produced by these sectors are exported outside the Tri-Cities. In addition to the direct employment and payrolls, these major sectors also support a sizable number of jobs in the local economy through their procurement of equipment, supplies, and business services.

In addition to these three major employment sectors, three other components can be readily identified as contributors to the economic base of the Tri-Cities. The first of these, loosely termed "other major employers," includes five major employers: 1) Siemens Nuclear Power Corporation, 2) Sandvik Special Metals, 3) Boise-Cascade, 4) Burlington Northern Railroad, and 5) Iowa Beef Processors. The second component is tourism. The Tri-Cities area has increased its convention business substantially in recent years, in addition to recreational travel. The final component in the economic base relates to the local purchasing power generated not from current employees but from retired former employees. Government transfer payments in the form of pension benefits constitute a significant proportion of total spendable income in the local economy.

4.7.1.1 DOE Contractors (Hanford)

Hanford continued to dominate the local employment picture with almost 25% of the total nonagricultural jobs in Benton and Franklin counties in 1994 (18,388 average of 72,300 average). Hanford's payroll has a widespread impact on the Tri-Cities and state economy in addition to providing direct employment. These effects are further described in Subsection 4.7.2.

4.7.1.2 Washington Public Power Supply System

Although activity related to nuclear power construction ceased with the completion of the WNP-2 reactor in 1983, the Supply System continues to be a major employer in the Tri-Cities area. Headquarters personnel based in Richland oversee the operation of one generating facility and perform a variety of functions related to a standby generating facility. Decommissioning of two mothballed nuclear power plants (WNP-1 and WNP-4) is expected to begin in 1995. The Supply System currently employs around 90 people at the two plants; this number may be cut in half by 1996 because of decommissioning activities. In 1994, the Supply System headquarters employment was more than 1700 workers. Supply System activities generated a payroll of approximately $83.6 million during 1994.

4.7.1.3 Agriculture

In 1993, agricultural production in the bicounty area generated about 9482 wage and salary jobs, or 12% of the area's total employment, as represented by the employees covered by unemployment insurance. Seasonal farm workers are not included in that total but are estimated by the U.S. Department of Labor for the agricultural areas in the state of Washington. In 1994, seasonal farm workers in Benton, Franklin, and Walla Walla counties averaged 6307, ranging from 1600 workers during the winter pruning season to 17,260 workers at the peak of harvest. An estimated average 4640 seasonal workers were classified as local (ranging from 1250 to 9220); an average of 423 were classified as intrastate (ranging from 0 to 2211); and an average of 1245 were classified as interstate (ranging from 0 to 5830). Most intrastate workers resided elsewhere in Benton, Franklin, Walla Walla, and Yakima counties, although the peak harvest season saw an influx of workers from around Eastern and Central Washington. The weighted seasonal wage for 1994 ranged from $5.18/hr to $5.80/hr, with an average of $5.44/hr (Washington State Employment Security 1994).

According to the U.S. Department of Commerce's Regional Economic Information System, about 2330 people were classified as farm proprietors in 1992. Farm proprietors' income, according to this same source, was estimated to be $82.9 million.

The area's farms and ranches generate a sizable number of jobs in supporting activities, such as agricultural services (e.g., application of pesticides and fertilizers and irrigation system development) and farm supply and equipment sales. Although formally classified as a manufacturing activity, food processing is a natural extension of the farm sector. More than 20 food processors in Benton and Franklin counties produce such items as potato products, canned fruits and vegetables, wine, and animal feed.

4.7.1.4 Other Major Employers

In 1994, other major employers (Siemens Nuclear Power Corporation, Sandvik Special Metals, Boise Cascade, Burlington Northern Railroad, and Iowa Beef Processors) employed approximately 3550 people in Benton and Franklin counties. Although Boise Cascade's Wallula mill lies outside both Benton and Franklin counties, most of its workforce resides in the Tri-Cities.

4.7.1.5 Tourism

The Tri-Cities Visitors and Convention Bureau reported approximately 320 conventions were held in the Tri-Cities in 1994, with 52,428 attending visitors who spent an estimated $17.3 million. The number of conventions and visitors is up 40% from levels reported in 1993, while the dollar volume generated by visitors is up nearly 47%.

A study by the Washington State Tourism Development Division estimated that overall tourism expenditures in the Tri-Cities were roughly $143.5 million in 1993 and that travel-generated employment in Benton and Franklin counties was about 2300 with an estimated $25.2 million in payroll.

4.7.1.6 Retirees

Although Benton and Franklin counties have a relatively young population (approximately 55% under the age of 35), 16,406 people over the age of 65 resided in Benton and Franklin counties in 1994. The portion of the total population 65 years and older in Benton and Franklin counties accounts for 9.8% of the total population, slightly below that of the state of Washington (11.6%). This segment of the population supports the local economy on the basis of income received from government transfer payments and pensions, private pension benefits, and prior individual savings.

Although information on private pensions and savings is not available, data are available regarding the magnitude of government transfer payments. The U.S. Department of Commerce's Regional Economic Information System has estimated transfer payments by various programs at the county level. A summary of estimated major government pension benefits received by the residents of Benton and Franklin counties in 1991 is shown in Table 4.7-1. About two-thirds of Social Security payments go to retired workers; the remainder are for disability and other payments. The historical importance of government activity in the Tri-Cities area is reflected in the relative magnitude of the government employee pension benefits as compared to total payments.

4.7.1.7 Secondary Sector

The secondary sector consists of all workers not employed by Hanford or the other major employers in Benton and Franklin counties. Table 4.7-2 provides a breakdown of nonagricultural wage and salary workers employed in Benton and Franklin counties in 1994 (Washington State Employment Security 1994).

Table 4.7-1. Government retirement payments in Benton and Franklin counties, 1991 (millions of dollars).[a]

	Benton County	Franklin County	Total
Social Security (including survivors and disability)	129.5	34.8	164.3
Railroad retirement	3.2	4.1	7.3
Federal civilian retirement	11.5	2.8	14.3
Veterans pension and military retirement	17.1	3.6	20.7
State and local employee retirement	24.3	4.8	29.1
Total	185.6	50.1	235.7

(a) U.S. Department of Commerce (1994).

Nonagricultural jobs increased by 2800 during 1994 (a 4.1% growth rate). During this time period, manufacturing employment rose by 200; transportation, communication, and public utility employment rose by 100; trade was up by 800; finance, insurance, and real estate employment grew by 300; and government employment was up by 400 (Washington State Employment Security 1994). Employment growth for 1994 is predicted to be 3.25 to 3.75%, slightly lower than in 1993.

Table 4.7-2. Nonagricultural workers in Benton and Franklin counties, 1993 and 1994.

Industry	1994 Annual Average	1993 Annual Average	% Change 1993-1994
Nonagricultural wage laborers	72,300	69,500	4
Manufacturing	5,500	5,000	3
Construction[a]	4,000	4,400	-9
Public utilities	2,200	2,100	5
Wholesale and retail trade	15,000	14,100	6
Finance, insurance, and real estate	2,200	1,900	16
Services and mining[a]	30,300	28,800	5
Government	13,300	12,900	3

(a) During 1994, employees of one Hanford contractor were reclassified from construction to services, making actual changes in employment in these sectors difficult to determine.

4.7.1.8 Income

Three measures of income are presented in this section: total personal income, per capita income, and median household income. Total personal income is comprised of all forms of income received by the populace, including wages, dividends, and other revenues. Per capita income is roughly equivalent to total personal income divided by the number of people residing in the area. Median household income is the point at which half of the households have an income greater than the median and half have less. The source for total personal income and per capita income was the U.S. Department of Commerce's Regional Economic Information System, while median income figures for Washington State were provided by the Office of Financial Management (OFM 1994b).

In 1992, the total personal income for Benton County was $2422 million, Franklin County was $633 million, and the state of Washington was $109.5 billion. Per capita income in 1992 for Benton County was $20,122, Franklin County was $15,620, and Washington State was $21,289. Median income in 1992 for Benton County was estimated to be $40,288, Franklin County was estimated $28,317, and the state of Washington was estimated at $36,648.

4.7.2 Local and State Economy

In 1994, Hanford employment accounted directly for 25% of total nonagricultural employment in Benton and Franklin counties and slightly more than 0.8% of all nonagricultural state-wide jobs. The total wage payroll for the Hanford Site was estimated at $740 million in 1994, which accounted for an estimated 45% of the payroll dollars earned in the area. Downsizing activities during FY 1995 are expected to decrease the number of Hanford jobs by 4800 by the end of September 1995.

Previous studies have revealed that each Hanford job supports about 1.2 additional jobs in the local service sector of Benton and Franklin counties and about 1.5 additional jobs in the state's service sector (Scott et al. 1987). Similarly, each dollar of Hanford income supports about $2.10 of total local incomes and about $2.40 of total state-wide incomes. Based on these multipliers in Benton and Franklin counties, Hanford directly or indirectly accounts for more than 40% of all jobs.

Based on employee residence records as of December 1993, 93% of the direct employment of Hanford goes to residents of Benton and Franklin counties. Approximately 81% of the employment goes to residents who reside in Richland, Pasco, or Kennewick. More than 42% of the employment goes to Richland residents, 9% to Pasco residents, and 30% to Kennewick residents. West Richland, Benton City, Prosser, and other areas of Benton and Franklin counties account for 12% of total employment.

4.7.3 Demography

Estimates for 1994 placed population totals for Benton and Franklin counties at 127,000 and 42,899, respectively (OFM 1994b). When compared to the 1990 census data in which Benton County had 112,560 residents and Franklin County's population totaled 37,473, the current population totals reflect the continued growth occurring in these two counties.

Within each county, the 1994 estimates distributed the Tri-Cities population as follows: Richland 35,430; Pasco 22,170; and Kennewick 46,960. The combined populations of Benton City, Prosser, and West Richland totaled 11,985 in 1994. The unincorporated population of Benton County was 32,610. In Franklin County, incorporated areas other than Pasco have a total population of 3,155. The unincorporated population of Franklin County was 17,575 (OFM 1994b).

The 1994 estimates of racial categories by the Office of Financial Management (OFM 1994b) indicate that in Benton and Franklin counties, Asians represent a lower proportion and individuals of Hispanic origin represent a higher proportion of the racial distribution than those in the state of Washington. Countywide, Benton and Franklin counties exhibit varying racial distributions, as indicated by the data in Table 4.7-3.

Benton and Franklin counties accounted for 3.2% of Washington State's population (OFM 1994a). In 1994, the population demographics of Benton and Franklin counties are quite similar to those found within the state of Washington. Fifty-five percent of the population of Benton and Franklin counties is under the age of 35, compared to 52% for the state of Washington. Within the state of Washington, 30- to 39-year olds constitute the largest age group (17.6%) compared to 16.8% found within Benton and Franklin counties. In general, the population of Benton and Franklin counties is somewhat younger than that of Washington State. The 0- to 14-year old age group accounts for 27.1% of the total bicounty population as compared to 22.7% for Washington State. In 1994, the 65-year old and older age group constituted 9.8% of the population of Benton and Franklin counties compared to 11.6% for the state of Washington.

4.7.4 Environmental Justice

Environmental justice refers to fair treatment of all races, cultures, and income levels with respect to laws, policies, and government actions. Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low Income Populations*, directs federal agencies to identify and address, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority and low-income populations.

This section uses the following definitions:

- **minority**-individuals classified by the U.S. Bureau of the Census as Negro/Black/African American, Hispanic, Asian and Pacific Islander, American Indian, Eskimo, Aleut, and other non-White persons. The minority population in an affected area is the number of individuals residing in the area who are members of a minority group.

- **low-income community**-an area for which the median household income is 80% or more below the median household income for the metropolitan statistical area (urban) or county (rural). "80 percent" is used based on definitions used by the U.S. Department of Housing and Urban Development.

The distribution of minority populations residing in various areas surrounding the Hanford Site in 1990 is shown in Table 4.7-4. The table shows minority populations within an 80-km (50-mi) radius.

Table 4.7-3. Population estimates by the U.S. Bureau of the Census racial categories and Hispanic origin, 1994.[a]

Area	Total	White	Black	Indian, Eskimo, and Aleut	Asian and Pacific Islander	Other n.e.c.[b]	Hispanic Origin[c]
Washington State	5,334,400	4,629,077 86.8%	176,487 3.3%	92,401 1.7%	283,783 5.3%	152,652 2.9%	284,190 5.3%
Benton and Franklin Counties[d]	169,900	140,237 82.5%	2,712 1.6%	1,310 0.8%	4,480 2.6%	21,161 12.5%	29,022 17.1%
Benton County[d]	127,000	113,569 89.4%	1,400 1.1%	992 0.8%	3,113 2.5%	7,926 9.7%	12,360 9.7%
Franklin County[d]	42,900	26,668 62.2%	1,312 3.1%	318 0.7%	1,367 3.2%	13,235 30.9%	16,662 38.8%

(a) From OFM 1994b, Table 21 - Population Estimates by Bureau of the Census Racial Categories and for the Hispanic Origin Population by County: April 1994.

(b) The "Other n.e.c." racial category is a count of persons who marked "Other Race" on the 1990 census questionnaire and wrote in entries such as Cuban, Puerto Rican, or Mexican.

(c) Hispanic Origin is not a racial category: it may be viewed as the ancestry, nationality group, lineage, or country of birth of the person or person's parents or ancestors before arrival in the United States. Persons of hispanic origin may be of any race and are counted in the racial categories shown.

(d) Percentage figures refer to county, not state, populations.

For comparison, minority populations are also shown for those counties with boundaries at least partially within the circle. Counties included in the circle are Benton, Franklin, Walla Walla, Adams, Grant, Kittitas, Yakima, and Klickitat in Washington State; and Umatilla in Oregon.

Figure 4.7-1 shows the distribution of minorities residing within 80 km (50 mi) of the Hanford Site. This illustration was obtained from an analysis of 1990 census data using a geographical information system. The data were obtained from U.S. Bureau of the Census Tiger Line files, which contain political boundaries and geographical features, and Summary Tape Files, which contain demographic information. Data were resolved to the block group level, usually 250 to 550 household units. In the legend of the figure, "P" denotes the percentage of the total population within block groups that are minority members. The most heavily shaded areas shown in this figure indicates block groups for which the minority population exceeds 50%.

Table 4.7-4. Distribution of minority populations in counties surrounding the Hanford Site, 1990.

Population within 80 km (50 mi) of the Site	383,934
Minority Population within 80 km (50 mi) of the Site	95,042
% of State Population within 80 km (50 mi) of the Site	24.8
Population in Counties Surrounding the Site	565,871
Minority Population in Counties Surrounding the Site	116,610
% of Minority Population in Counties Surrounding the Site	20.6

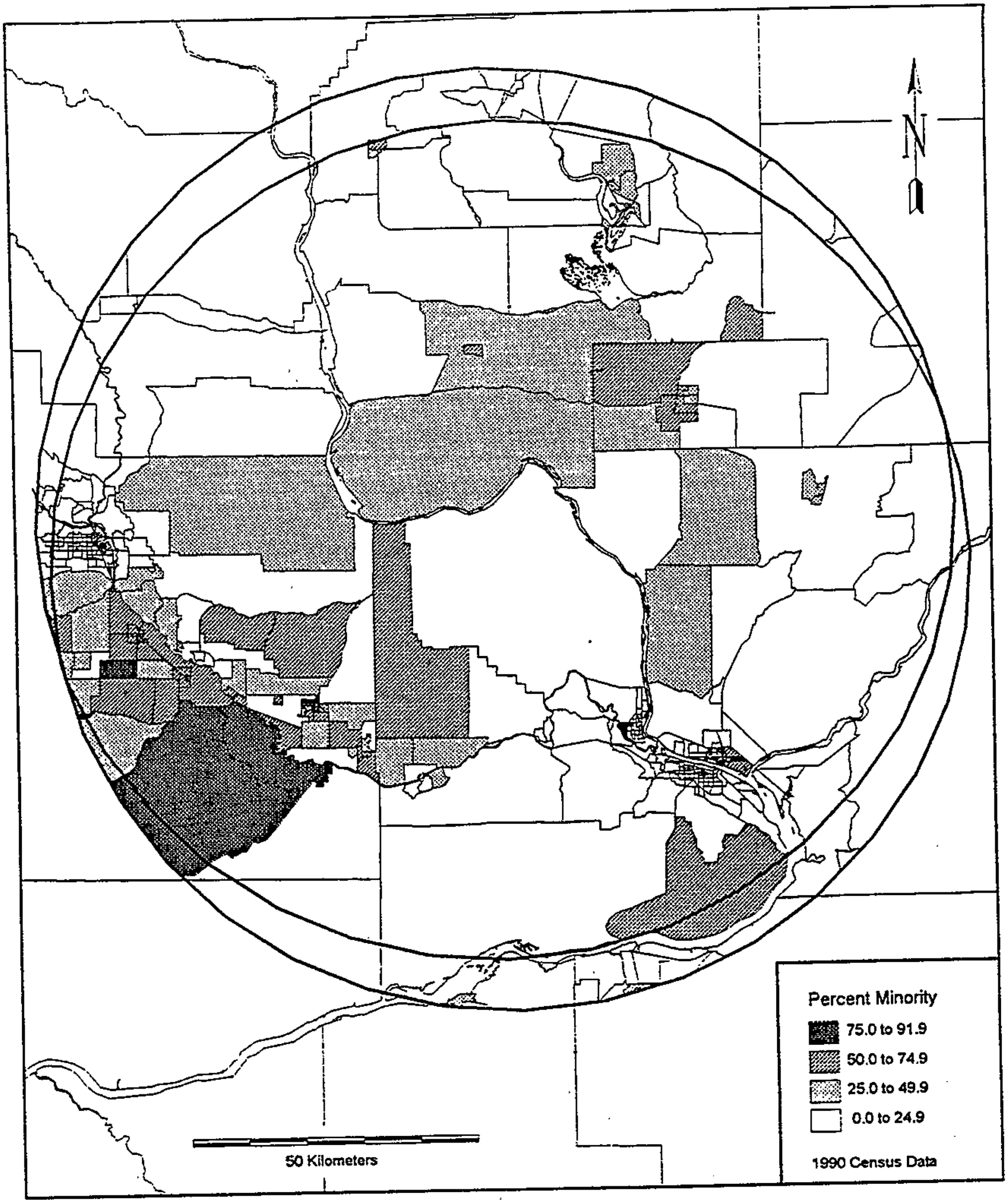

Figure 4.7-1. Distribution of minority populations within 80 km (50 mi) of the Hanford Site.

The racial and ethnic composition of minorities surrounding the Hanford Site is illustrated in Table 4.7-5. At the time of the 1990 census, Hispanics composed nearly 81% of the minority population surrounding the Hanford Site. The Site is also surrounded by a relatively large percentage (about 8%) of Native Americans because of the presence of the Yakama Indian Reservation and tribal headquarters in the Toppenish, Washington.

Table 4.7-6 demonstrates the number of low-income households in the area surrounding the Hanford Site. Block groups containing 50% or more low-income households lie largely south of the Site. Figure 4.7-2 shows the distribution of low-income households within 80 km (50 mi) of the Hanford Site.

4.7.5 Housing

In 1994, 95% of all housing (of 41,562 total units) in the Tri-Cities was occupied. Single-unit housing, which represents nearly 59% of the total units, has a 98% occupancy rate throughout the Tri-Cities. Multiple-unit housing, defined as housing with two or more units, has an occupancy rate of 95%, a 4% increase since 1990. Pasco has the lowest occupancy rate, 93%, in all categories of housing; followed by Kennewick with 96%, and Richland with 97%. Representing 11% of the housing unit types, mobile homes have the lowest occupancy rate, 90%. Table 4.7-7 shows a detailed listing of total units and occupancy rate by type in the Tri-Cities.

4.7.6 Transportation

The Tri-Cities serve as a regional transportation and distribution center with major air, land, and river connections. The Tri-Cities have direct rail service, provided by Burlington Northern and Union Pacific, that connects the area to more than 35 states. The Washington Central Railroad serves Eastern

Table 4.7-5. Racial and ethnic composition of minorities in counties surrounding the Hanford Site, 1990.

Category	Number	Percentage
Total Population within Surrounding Counties	383,934	100.0
Total Minority Population	95,042	24.8
American Indian, Eskimo, or Aleut Population	7,913	2.1
Asian or Pacific Islander Population	5,296	1.4
African American Population	4,331	1.1
Other Race	568	0.1
Hispanic Origin Population[(a)]	76,933	20.0
White	288,891	75.2

(a) Hispanic origin is not a racial category. It may be viewed as the ancestry, nationality group, lineage, or country of birth of the person or person's parents or ancestors before arrival in the United States. Persons of hispanic origin may be of any race and are counted in the racial categories shown.

Table 4.7-6. Distribution of low-income households in counties surrounding the Hanford Site, 1990.

Households within 80 km (50 mi) of the Site	136,496
Low-income Households within 80 km (50 mi) of the Site	57,667
% of Low-income Households within 80 km (50 mi) of the Site	42.2
Households in Counties Surrounding the Site	204,501
Low-income Households in Counties Surrounding the Site	86,693
% of Low-income Households in Counties Surrounding the Site	42.4

Washington as well. Union Pacific operates the largest fleet of refrigerated rail cars in the United States and is essential to food processors, which ship frozen food from this area. Passenger rail service is provided by Amtrak, which has a station in Pasco.

Docking facilities at the Ports of Benton, Kennewick, and Pasco are important aspects of this region's infrastructure. These facilities are located on the 525-km- (325.5-mi-long) commercial waterway, which includes the Snake and Columbia rivers, that extends from the Ports of Lewiston-Clarkston in Idaho to the deep-water ports of Portland, Oregon, and Vancouver, Washington. The average shipping time from the Tri-Cities to these deep-water ports by barge is 36 hours (Evergreen Community Development Association 1986).

Daily air passenger and freight services connect the area with most major cities through the Tri-Cities Airport, located in Pasco. The airport is currently served by one national and two commuter-regional airlines. There are two runways: a main and minor crosswind. The main runway is equipped for precision instrumentation landings and takeoffs. Each runway is 2347-m (7700-ft) long and 46-m (150-ft) wide, and can accommodate landings and takeoffs by medium-range commercial aircraft, such as the Boeing 727-200 and Douglas DC-9. The Tri-Cities Airport handled about 188,000 passengers (enplanements) in 1994. Projections indicate that the terminal can serve almost 300,000 passengers annually. Two additional airports, located in Richland and Kennewick, are limited to serving private aircraft.

The regional transportation network in the Hanford vicinity includes the areas in Benton and Franklin counties from which most of the commuter traffic associated with the Site originates. Interstate highways that serve the area are I-82, I-182, and I-90. Interstate-82 is 8 km (5 mi) south-southwest of the Site. Interstate-182, a 24-km- (15-mi-) long urban connector route, located 8 km (5 mi) south-southeast of the Site, provides an east-west corridor linking I-82 to the Tri-Cities area. I-90, located north of the Site, is the major link to Seattle and Spokane and extends to the East Coast; I-82 serves as a primary link between Hanford and I-90. State Route 224, south of the Site, serves as a 16-km (10-mi) link between I-82 and SR 240. State Route 24 enters the Site from the west, continues eastward across the northernmost portion of the Site, and intersects SR 17 approximately 24 km (15 mi) east of the Site boundary. State Route 17 is a north-south route that links I-90 to the Tri-Cities

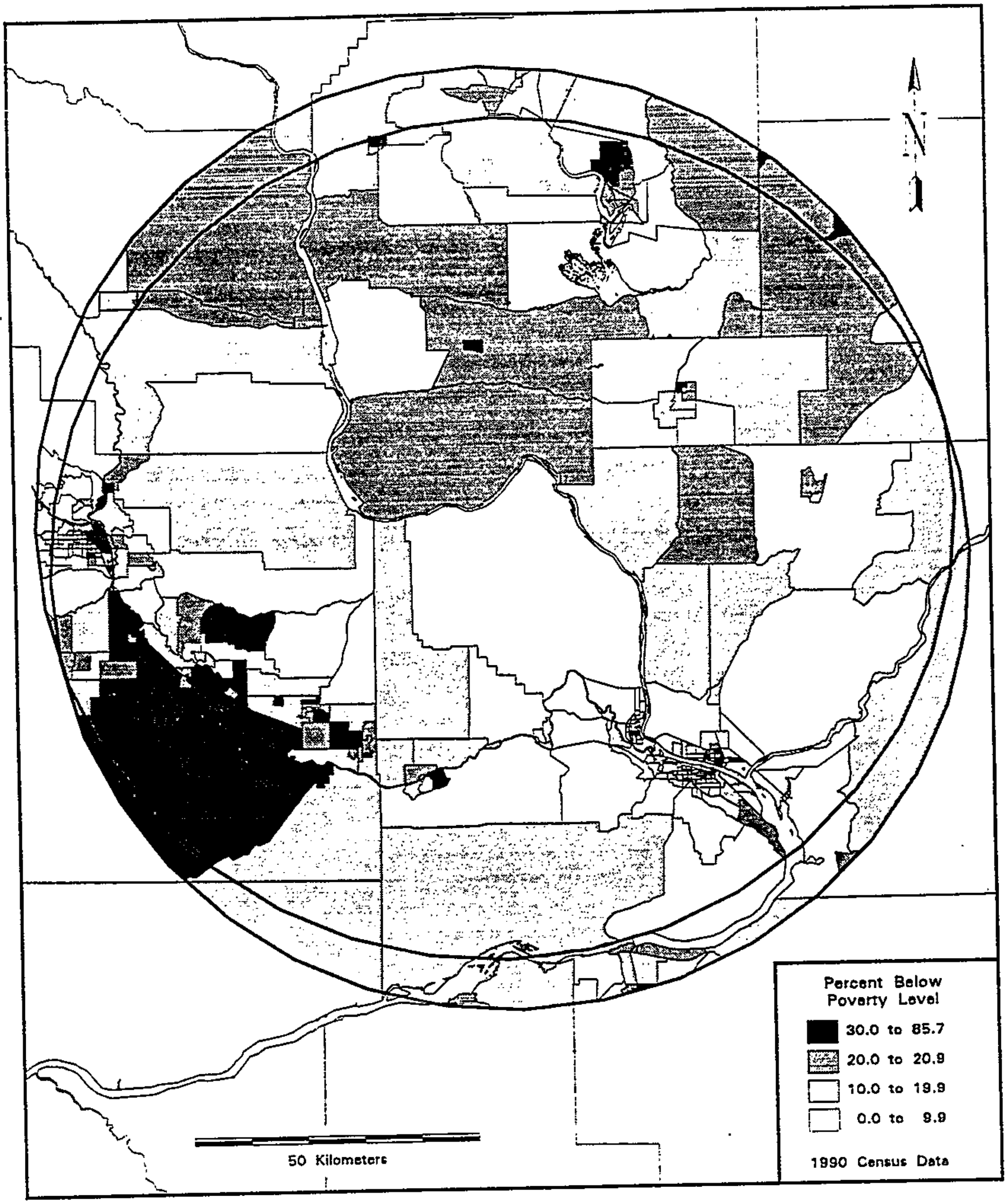

Figure 4.7-2. Distribution of low-income populations within 80 km (50 mi) of the Hanford Site.

Table 4.7-7. Total units and occupancy rates, estimates 1994.[a]

City	All Units	Rate %	Single Units	Rate %	Multipl e Units	Rate %	Manufactured Homes	Rate %
Richland	14,828	97	10,355	98	3,827	96	646	88
Pasco	8,035	93	3,802	97	2,933	93	1,300	86
Kennewick	18,699	96	10,179	98	5,961	97	2,559	97
Total for Tri-Cities	41,562	95	24,336	98	12,721	95	4,505	90

(a) OFM (1994).

and joins U.S. Route 395, which continues south through the Tri-Cities. State Route 14 connects with I-90 at Vantage, Washington, and provides ready access to I-84 at several locations along the Oregon and Washington border. State Routes 240 and 24 traverse the Hanford Site and are maintained by Washington State. Other roads within the Site are maintained by the DOE.

4.7.7 Educational Services

4.7.7.1 Primary and Secondary Education

Primary and secondary education are served by the Richland, Pasco, Kennewick, and Kiona-Benton School Districts. The combined 1994 spring enrollment for all districts was approximately 31,970 students, an increase of 7.4% from the 1993 total of 29,777 students. The 1994 total includes approximately 8665 from the Richland School District, 8739 students from the Pasco School District, about 13,012 students from the Kennewick School District, and 1550 from Kiona-Benton. In 1994, Richland was operating near capacity, Pasco was at capacity for primary education but had room for approximately 200 to 250 more students at the secondary level; Kennewick was at capacity at the primary level and over capacity at the secondary level; and Kiona-Benton was operating above capacity at all levels. The Kennewick School District is working on alleviating some of the overcrowded conditions by constructing a new high school, one new middle school, and two new elementary schools.

4.7.7.2 Post-Secondary Education

Post-secondary education in the Tri-Cities area is provided by a junior college, Columbia Basin College (CBC), and the Tri-Cities branch campus of Washington State University (WSU-TC). WSU-TC offers a variety of upper-division, undergraduate, and graduate degree programs. The 1994 fall enrollment was approximately 6839 at CBC and 1300 at WSU-TC. Many of the programs offered by these two institutions are geared towards the vocational and technical needs of the area. Currently, 23 associate degree programs are available at CBC, and WSU-TC offers 10 undergraduate and 15 graduate programs.

4.7.8 Health Care and Human Services

4.7.8.1. Health Care

The Tri-Cities have three major hospitals and five minor emergency centers. All three hospitals offer general medical services and include a 24-hour emergency room, basic surgical services, intensive care, and neonatal care.

Kadlec Medical Center, located in Richland, has 144 beds and functioned at 45.3% capacity in 1994. Their 5628 annual admissions represent more than 38% of the Tri-Cities market. Non-Medicare/Medicaid patients accounted for 55%, or 3101 of their annual admissions in 1994. An average stay of 3.92 days per admission was reported for 1994.

Kennewick General Hospital maintains a 45.7% occupancy rate of its 70 beds with 4731 annual admissions in 1994. Non-Medicare/Medicaid patients in 1994 represented 35% of its total admissions. An average stay of 3.2 days per admission was reported in 1994.

Our Lady of Lourdes Hospital operates a 132-bed Health Center, located in Pasco, providing acute, subacute, skilled nursing and rehabilitation, and alcohol and chemical dependency services. Our Lady of Lourdes also operates the Carondolet Psychiatric Care Center, a 32-bed psychiatric hospital located in Richland. They also provide a significant amount of outpatient and home health services. For their FY ending June 30, 1994, Our Lady of Lourdes had a total of 4449 admissions of which 32.8% were non-Medicare/Medicaid admissions. Lourdes had an average acute care length of stay of 3.1 days.

4.7.8.2 Human Services

The Tri-Cities offers a broad range of social services. State human service offices in the Tri-Cities include the Job Services office of the Employment Security Department; Food Stamp offices; the Division of Developmental Disabilities; Financial and Medical Assistance; the Child Protective Service; emergency medical service; a senior companion program; and vocational rehabilitation.

The Tri-Cities are also served by a large number of private agencies and voluntary human services organizations. The United Way, an umbrella fund-raising organization, incorporates 24 participating agencies offering more than 48 programs. These member agencies had a cumulative budget total of $21.1 million in 1994.[a] In addition, there were 407 organizations that received funds as part of the United Way-Franklin County donor designation program.

4.7.9 Police and Fire Protection

Police protection in Benton and Franklin counties is provided by Benton and Franklin counties' sheriff departments, local municipal police departments, and the Washington State Patrol Division headquartered in Kennewick. Table 4.7-8 shows the number of commissioned officers and patrol cars

(a) Personal communication with Jim Ball, President of Benton-Franklin United Way, 1995.

Table 4.7-8. Police personnel in the Tri-Cities, 1995.[a]

Area	Commissioned Officers	Reserve Officers	Patrol Cars
Kennewick Municipal	66	22	18
Pasco Municipal	43	26	13
Richland Municipal	44	23	18
West Richland Municipal	9	8	9
Benton County Sheriff	43	20	50
Franklin County Sheriff	21	15	21

(a) Source: personal communication with each department office, February 1995.

in each department in February 1995. The Kennewick, Richland, and Pasco municipal departments maintain the largest staffs of commissioned officers with 66, 44, and 43, respectively.

Table 4.7-9 indicates the number of firefighting personnel, both paid and unpaid, on the staffs of fire districts in the area.

The Hanford Fire Department, with 155 firefighters, is trained to dispose of hazardous waste and to fight chemical fires. During the 24-hour duty period, the 1100 Area has 5 firefighters; 300 Area has 7; 200 East and 200 West Areas have 7; the 100 Areas have 6; and the 400 Area, which includes the Supply System, has 6. To perform their responsibilities, each station has access to a Hazardous Material Response Vehicle that is equipped with chemical fire-extinguishing equipment, an attack truck

Table 4.7-9. Fire protection in the Tri-Cities, 1995.[a]

Station[b]	Fire Fighting Personnel	Volunteers	Total	Service Area
Kennewick	57	0	57	City of Kennewick
Pasco	30	0	30	City of Pasco
Richland	56	0	56	City of Richland
BCRFD 1	5	100	105	Kennewick Area
BCRFD 2	0	30	30	Benton City
BCRFD 4	4	30	34	West Richland

(a) Source: personal communication with each department office, February 1995.
(b) BCRFD = Benton County Rural Fire Department.

that carries foam and Purple-K dry chemical, a mobile air truck that provides air for gas masks, and a transport tanker that supplies water to six brushfire trucks. The Hanford Fire Department owns five ambulances and maintains contact with local hospitals. The Hanford Fire Department is currently involved in discussions with DOE, the city of Richland, and Westinghouse Hanford Company regarding the possibility of contracting with the city of Richland for Hanford's fire protection services.

4.7.10 Parks and Recreation

The convergence of the Columbia, Snake, and Yakima rivers offers the residents of the Tri-Cities a variety of recreational opportunities.

The Lower Snake River Project includes Ice Harbor, Lower Monumental, Little Goose, and Lower Granite locks and dams, and a levee system and parkway at Clarkston and Lewiston. While navigation capabilities and the electrical output are the major benefits of this project, recreational benefits have also resulted. The Lower Snake River Project provides boating, camping, and picnicking facilities in nearly a dozen areas along the Snake River. In 1993, over 2.5 million people visited the area and participated in activities along the river.

Similarly, the Columbia River provides ample water recreational opportunities on the lakes formed by the dams. Lake Wallula, formed by McNary Dam, offers a large variety of parks and activities, which attracted more than 3 million visitors in 1993. The Columbia River Basin is also a popular area for migratory waterfowl and upland game bird hunting.

Other opportunities for recreational activities in the Tri-Cities are accommodated by the indoor and outdoor facilities available, some of which are listed in Table 4.7-10. Numerous tennis courts, ball fields, and golf courses offer outdoor recreation to residents and tourists. Several privately owned health clubs in the area offer indoor tennis and racquetball courts, pools, and exercise programs. Bowling lanes and roller skating rinks also serve the Tri-Cities.

4.7.11 Utilities

4.7.11.1 Water

The principal source of water in the Tri-Cities and the Hanford Site is the Columbia River. The water systems of Richland, Pasco, and Kennewick draw a large portion of the 49 billion L (12.94 billion gal) used in 1994 from the Columbia River. Each city operates its own supply and treatment system. The Richland water supply system derives about two-thirds of its water from the Columbia River, while the remainder is split between a well field in North Richland and groundwater wells. The city of Richland's total usage in 1994 was 26 billion L (6.90 billion gal). This usage represents approximately 63% of the maximum supply capacity. The city of Pasco system also draws from the Columbia River for its water needs. In 1994, Pasco consumed 8.6 billion L (2.27 billion gal). The Kennewick system uses two wells and the Columbia River for its supply. These wells serve as the sole source of water between November and March and can provide approximately 62% of the total maximum supply of 27.6 billion L (7.3 billion gal). Total 1994 usage in Kennewick was 14.6 billion L (3.86 billion gal).

Table 4.7-10. Examples of physical recreational facilities available in the Tri-Cities.

Activity	Facilities
Ball	Baseball fields and basketball courts are located throughout the Tri-Cities. Soccer and football fields are also located in various areas.
Bowling	Lanes in each city including Fiesta Bowling Center, Celebrity Bowl, Columbia Lanes, and Go-Bowl.
Camping	Several hundred campsites within driving distance from the Tri-Cities area, including Levy Park, Fishhook Park, and Sun Lakes.
Fishing	Steelhead, sturgeon, trout, walleye, bass, and crappie fishing in the lakes and rivers near the Tri-Cities.
Golf	6 public courses including Canyon Lakes, Horn Rapids, and West Richland Municipal, two private courses, and a number of driving ranges and pro shops are available.
Hunting	Duck, geese, pheasant, and quail hunting. Deer and elk hunting in the Blue Mountains and the Cascade Range.
Roller skating	Roller skating in Richland, Kennewick, and Prosser.
Swimming	Private and public swimming pools in the area. Boating, water-skiing, and swimming on the Columbia River.
Tennis	20 outdoor city courts, with additional outdoor courts located at area schools.

The major incorporated areas of Benton and Franklin counties are served by municipal wastewater treatment systems, whereas the unincorporated areas are served by onsite septic systems. Richland's wastewater treatment system is designed to treat a total capacity of 113.5 million L/d (30 million gal/d) and processed an average flow of 71.4 million L/d (18.87 million gal/d) in 1994. In 1993, the system processed an average 65.9 million L/d (17.4 million gal/d). The Kennewick system similarly has significant excess capacity; with a treatment capability 83.2 million L/d (22 million gal/d), 1994 usage was 40 million L/d (10.56 million gal/d). Pasco's waste treatment system processed an average 23.5 million L/d (6.22 million gal/d) while the system is capable of treating 94.6 million L/d (25 million gal/d).

4.7.11.2 Electricity

In the Tri-Cities, electricity is provided by the Benton County Public Utility District, Benton Rural Electrical Association, Franklin County Public Utility District, and City of Richland Energy Services Department. All the power that these utilities provide in the local area is purchased from the Bonneville Power Administration (BPA), a federal power marketing agency. The average rate for residential customers served by the three local utilities is approximately $0.052/kWh. Electrical power for the Hanford Site is purchased wholesale from BPA. Energy requirements for the Site during FY 1994 exceeded 338 million kWh for a total cost of nearly $9 million.

Natural gas, provided by the Cascade Natural Gas Corporation, serves a small portion of residents, with 6000 residential customers in December 1994.

In the Pacific Northwest, hydropower, and to a lesser extent, coal and nuclear power, constitute the region's electrical generation system. The system is capable of delivering approximately 20,300 average megawatts of guaranteed energy. Of that, approximately 62% is derived from hydropower, 16% from coal, and less than 7% from nuclear plants. One commercial nuclear power plant remains in service in the Pacific Northwest, with an average generating capability of 833 megawatts. The Trojan nuclear power plant, in Oregon, was permanently shut down on January 4, 1993.

The region's electrical power system, more than any other system in the nation, is dominated by hydropower. In a given peak demand hour, the hydropower system is capable of providing nearly 30,000 megawatts of capacity. Variable precipitation and limited storage capabilities alter the system's output from 12,300 average megawatt under critical water conditions to 20,000 average megawatt in record high-water years. The Pacific Northwest system's reliance on hydroelectric power means that it is more constrained by the seasonal variations in peak demand than in meeting momentary peak demand.

Additional constraints on hydroelectric production are measures designed to protect and enhance the production of salmon, as many salmon runs have dwindled to the point of being threatened or endangered. These measures, outlined by the Northwest Power Planning Council's (NPPC) Columbia River Basin Fish and Wildlife Program, include minimum flow levels and a "water budget," which refers to water in the Columbia and Snake rivers that is released to speed the migration of young fish to the sea. Generation capacity of the hydroelectric system is decreased with these measures, as less water is available to pass through the turbines.

Throughout the 1980s, the Pacific Northwest had more electric power than it required and was operating with a surplus. This surplus has been exhausted, however, and there is only enough power supplied by the system to meet regional electricity needs. In the 1991 Northwest Power Plan, the NPPC set a goal of purchasing more than 1500 megawatts of energy savings by the year 2000 to help the existing system meet with rising electricity demand. NPPC estimates that the Pacific Northwest will need an additional 2000 megawatts over 1991 consumption by the turn of the century.

4.7.12 Land Use

The Hanford Site encompasses 1,450 km^2 (560 mi^2) and includes several DOE operational areas. The entire Hanford Site has been designated a National Environmental Research Park. The major areas on the Site are as follows:

- The 100 Areas, bordering on the right bank (south shore) of the Columbia River, are the sites of eight retired plutonium production reactors and the N Reactor. The facilities in the 100 Areas are being placed in a stabilized state for ultimate decommissioning. The N Reactor Deactivation Program covers the period from FY 1992 through FY 1997. The 100 Areas occupy about 11 km^2 (4 mi^2).

- The 200 West and 200 East Areas are located on a plateau about 8 and 11 km (5 and 7 mi), respectively, from the Columbia River. These areas have been dedicated for some time to fuel reprocessing and waste management and disposal activities. The 200 Areas cover about 16 km^2 (6 mi^2).

- The 300 Area, located just north of the city of Richland, is the site of nuclear research and development. This area covers 1.5 km^2 (0.6 mi^2).

- The 400 Area is about 8 km (5 mi) north of the 300 Area and is the site of the Fast Flux Test Facility used in the testing of breeder reactor systems. In December 1993, the Secretary of Energy ordered the Fast Flux Test Facility to be shut down, and the process has begun. The goal is to reach a radiologically and industrially safe shutdown in approximately 5 years. Also included in this area is the Fuels and Materials Examination Facility.

- The 600 Area includes all of the Hanford Site not occupied by the 100, 200, 300, or 400 Areas. Land uses within the 600 Area include the following:

    1. 310 km^2 (120 mi^2), known as the ALE Reserve, is set aside for ecological studies. This area is expected to be excessed by DOE; however, the future use of this site is still under consideration. Proposals from interested parties include conservation plans and land use planning and development.

    2. 0.4 km^2 (0.2 mi^2) is leased by Washington State, a part of which is used for commercial low-level radioactive waste disposal.

    3. 4.4 km^2 (1.6 mi^2) is used by the Supply System for nuclear power plants.

    4. 2.6 km^2 (1 mi^2) is held by Washington State as a potential site for the disposal of nonradioactive hazardous wastes.

5. about 130 km^2 (50 mi^2) is under revocable use permit to the U.S. Fish and Wildlife Service for a wildlife refuge.

6. 225 km^2 (87 mi^2) is under revocable use permit to the Washington State Department of Fish and Wildlife for recreational game management (the Wahluke Wildlife Area).

7. support facilities for the controlled access areas.

An area of 665 km^2 (257 mi^2) has been designated for ALE, the U.S. Fish and Wildlife Service, wildlife refuges, and the Washington State Department of Game management area (DOE 1986).

The area known as the Hanford Reach includes the quarter-mile strip of public land on either side of the Columbia River in addition to the Saddle Mountain National Wildlife Refuge and the Wahluke Wildlife Area on the Wahluke Slope. The Hanford Reach is the last free-flowing, nontidal segment of the Columbia River in the United States. In 1988, Congress passed Public Law 100-605, known as the Comprehensive River Conservation Study Act, which required the Secretary of the Interior to prepare a study in consultation with the Secretary of Energy to evaluate the outstanding feature of the Reach and its immediate environment. Also, alternatives for preserving those features were examined, including the designation of the Reach as part of the National Wild and Scenic Rivers System. The results of the study can be found in the two-volume report, *Hanford Reach of the Columbia River - Comprehensive River Conservation Study and Environmental Impact Statement* (U.S. Department of Interior 1994). The preferred alternative was to designate the lands in the Hanford Reach as a wildlife refuge with a recreational river designation for the river.

The Columbia River, which is adjacent to and runs through the Hanford Site, provides access to the public for boating, water skiing, fishing, and hunting of upland game birds and migratory waterfowl. Some land access along the shore and on certain islands is available for public use.

Land use in other areas includes urban and industrial development, irrigated and dry-land farming, and grazing. In 1993, wheat represented the largest single crop in terms of area planted in Benton, Franklin, and Grant counties. Total acreage planted in the three counties was 207,890 ha (513,700 acres) and 24,120 ha (59,600 acres) for winter and spring wheat, respectively. Alfalfa, apples, asparagus, cherries, corn, grapes, and potatoes are other major crops in Benton, Franklin, and Grant counties.

In 1992, the Columbia Basin Project, a major irrigation project to the north of the Tri-Cities, produced gross crop returns of $552 million, representing 12.5% of all crops grown in Washington State. In 1992, the average gross crop value per irrigated acre was $1042. The largest percentage of irrigated acres produced alfalfa hay (26.1% of irrigated acres), wheat (20.2%), and feed-grain corn (5.8%). Other significant crops are apples, dry beans, potatoes, and sweet corn.

4.7.13 Visual Resources

The land near the Hanford Site is generally flat with little relief. Rattlesnake Mountain, rising to 1060 m (3477 ft) above mean sea level, forms the western boundary of the Site, and Gable Mountain and Gable Butte are the highest land forms within the Site. The view towards Rattlesnake Mountain is visually pleasing, especially in the springtime when wildflowers are in bloom. Large rolling hills are located to the west and far north. The Columbia River, flowing across the northern part of the Site and forming the eastern boundary, is generally considered scenic, with its contrasting blue against a background of brown basaltic rocks and desert sagebrush. The White Bluffs, steep whitish-brown bluffs adjacent to the Columbia River and above the northern boundary of the river in this region, are a strong feature of the landscape.

4.8 Noise

Noise is technically defined as sound waves perceptible to the human ear. Sound waves are characterized by frequency, measured in Hertz (Hz), and sound pressure expressed as decibels (dB). Humans have a perceptible hearing range of 31 to 20,000 Hz. The decibel is a value equal to 10 times the logarithm of the ratio of a sound pressure squared to a standard reference sound-pressure level (20 micropascals) squared. The threshold of audibility ranges from about 60 dB at a frequency of 31 Hz to less than about 1 dB between 900 and 8000 Hz. (For regulatory purposes, noise levels for perceptible frequencies are weighted to provide an A-weighted sound level [dBA] that correlates highly with individual community response to noise.) Sound pressure levels outside the range of human hearing are not considered noise in a regulatory sense, even though wildlife may be able to hear at these frequencies.

Noise levels are often reported as the equivalent sound level (Leq). The Leq is expressed in A-weighted sound level (dBA) over a specified period of time, usually 1 or 24 hours. The Leq is the equivalent steady sound level that, if continuous during a specified time period, would contain the same total energy as the actual time-varying sound over the monitored or modeled time period.

4.8.1 Background Information

Studies of the propagation of noise at Hanford have been concerned primarily with occupational noise at work sites. Environmental noise levels have not been extensively evaluated because of the remoteness of most Hanford activities and isolation from receptors that are covered by federal or state statutes. This discussion focuses on what few environmental noise data are available. The majority of available information consists of model predictions, which in many cases have not been verified because the predictions indicated that the potential to violate federal or state standards is remote or unrealistic.

4.8.2 Environmental Noise Regulations

The Noise Control Act of 1972 and its subsequent amendments (Quiet Communities Act of 1978 and 40 CFR 201-211) direct the regulation of environmental noise to the state. The state of Washington has adopted RCW 70.107, which authorizes the Washington State Department of Ecology to implement rules consistent with federal noise control legislation. RCW 70.107 and the implementing regulations embodied in WAC 173-60 through 173-70 defined the regulation of environmental noise levels. Maximum noise levels are defined for the zoning of the area in accord with environmental designation for noise abatement (EDNA). The Hanford Site is classified as a Class C EDNA on the basis of industrial activities. Unoccupied areas are also classified as Class C areas by default because they are neither Class A (residential) or Class B (commercial). Maximum noise levels are established based on the EDNA classification of the receiving area and the source area (Table 4.8-1).

4.8.3 Hanford Site Sound Levels

Most industrial facilities on the Hanford Site are located far enough away from the Site boundary that noise levels at the boundary are not measurable or are barely distinguishable from background noise levels. Modeling of environmental noises has been performed for commercial reactors and State Route 240 through the Hanford Site. These data are not concerned with background levels of noise and are not reviewed here. There are two sources of measured environmental noise at Hanford. Environmental noise measurements were made in 1981 during site characterization for the Skagit/Hanford Nuclear Power Plant Site (NRC 1982). Measurements were also made when the Hanford Site was considered for a geologic waste repository (Basalt Waste Isolation Project, BWIP) for spent commercial nuclear fuel and other high-level nuclear waste. Site characterization studies performed in 1987 included measurement of background environmental noise levels at five locations on the Hanford Site. Additionally, certain activities such as well drilling and sampling have the potential for producing noise in the field apart from major permanent facilities.

Recently, the potential impact of traffic noise resulting from Hanford Site activities has been evaluated for a draft environmental impact statement addressing the siting of the proposed New Production Reactor (NPR [DOE 1991]). While this environmental impact statement does not include any new baseline measurements, it does address the traffic component of noise and provides modeled "baseline" measurements of traffic noise for the Hanford Site and adjacent communities.

4.8.3.1 Skagit/Hanford Data

Preconstruction measurements of environmental noise were taken in June 1981 on the Hanford Site (NRC 1982). Fifteen sites were monitored, and noise levels ranged from 30 to 60.5 dBA (Leq). The values for isolated areas ranged from 30 to 38.8 dBA. Measurements taken around the sites where the Supply System was constructing nuclear power plants (WNP-1, WNP-2, and WNP-4) ranged from 50.6 to 64 dBA. Measurements taken along the Columbia River near the intake structures for WNP-2 were 47.7 and 52.1 dBA compared with more remote river noise levels of 45.9 dBA (measured about 4.8 km or 3 mi upstream of the intake structures). Community noise levels in North Richland (Horn Rapids Road and Highway 12) were 60.5 BA.

Table 4.8-1. Applicable state noise limitations for the Hanford Site based on source and receptor EDNA designation (values are dBA).

Source Hanford Site	Receptor: Class A Residential	Receptor: Class B Commercial	Receptor: Class C Industrial
Class C - Day	60	65	70
Night	50	--	--

4.8.3.2 BWIP Data

Background noise levels were determined at five locations within the Hanford Site (Figure 4.8-1). Noise levels are expressed as equivalent sound levels for 24 hours (Leq-24). Sample location, date, and Leq-24 are listed in Table 4.8-2. Wind was identified as the primary contributor to background noise levels, with winds exceeding 19 km/h (12 mi/h) significantly affecting noise levels. Coleman concludes that background noise levels in undeveloped areas at Hanford can best be described as a mean Leq-24 of 24 to 36 DBA. Periods of high wind, which normally occur in the spring, would elevate background noise levels.

4.8.3.3 NPR EIS

Baseline noise estimates were determined for two locations: State Route (SR) 24, leading from the Hanford Site west to Yakima, and SR 240, south of the Site and west of Richland where it handles maximum traffic volume (DOE 1991). Traffic volumes were predicted based on an operational work force and a construction work force. Both peak (rush hour) and off-peak hours were modeled. Noise levels were expressed in Leq for 1-hour periods in dBA at a receptor located 15 m (49 ft) from the road edge (Table 4.8-3). Adverse community responses would not be expected at increases of 5 dBA over background noise levels.

4.8.3.4 Noise Levels of Hanford Field Activities

In the interest of protecting Hanford workers and complying with Occupational Safety and Health Administration (OSHA) standards for noise in the workplace, the Hanford Environmental Health Foundation has monitored noise levels resulting from several routine operations performed at Hanford. Occupational sources of noise propagated in the field have been summarized in Table 4.8-4. These levels are reported here because operations such as well sampling are conducted in the field away from established industrial areas and have the potential for disturbing sensitive wildlife.

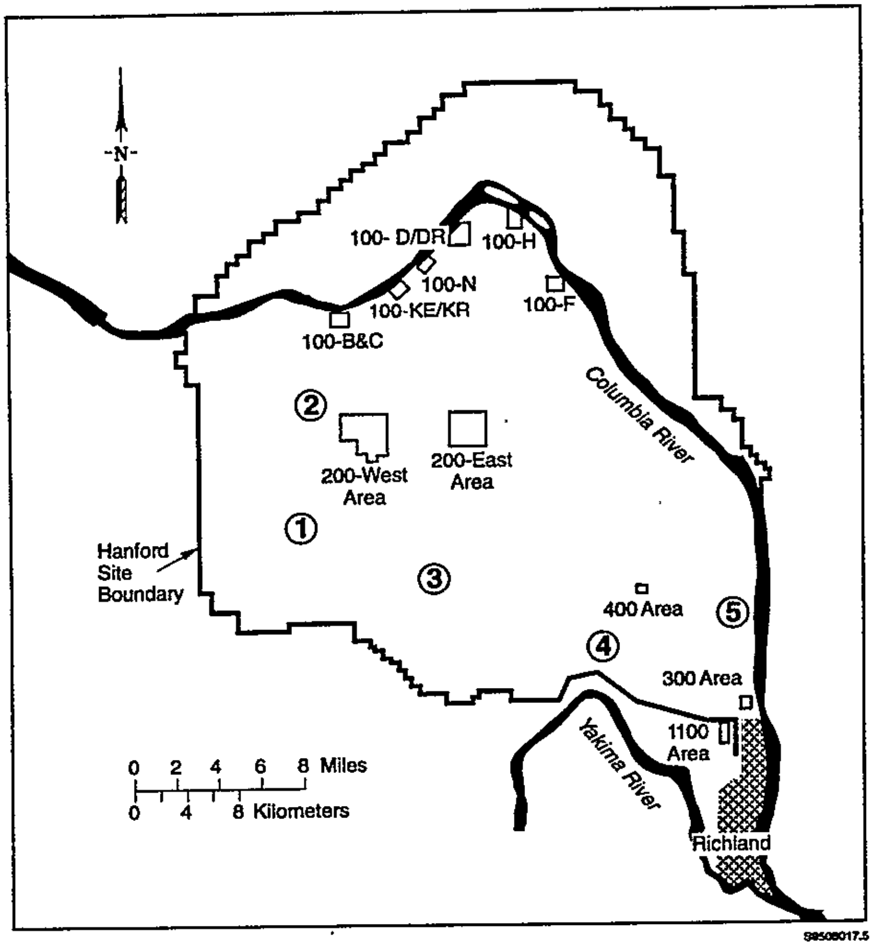

Figure 4.8-1. Location of background noise measurements (see Table 4.8-2).

Table 4.8-2. Background noise levels measured at isolated areas.

Site	Location: Section	Range	Township	Date	Leq-24 (dBA)
1	9	R25E	T12N	07-10-87	41.7
				07-11-87	40.7
				07-12-87	36.0
				07-13-87	37.2
				07-14-87	35.6
2	26	R25E	T13N	07-25-87	43.9
				07-26-87	38.8
				07-27-87	43.8
				07-28-87	37.7
				07-29-87	43.2
3	18	R26E	T12N	08-08-87	39.0
				08-09-87	35.4
				08-10-87	51.4[a]
				08-11-87	56.7[a]
				08-12-87	36.0
4	34	R27E	T11N	09-09-87	35.2
				09-10-87	34.8
				09-11-87	36.0
				09-12-87	33.2
				09-13-87	37.3
5	14	R28E	T11N	10-15-87	40.8
				10-16-87	36.8
				10-17-87	33.7
				10-18-87	31.3
				10-19-87	35.9

(a) Leq includes grader noise.

Table 4.8-3. Modeled noise resulting from automobile traffic at Hanford in association with the New Production Reactor environmental impact statement (DOE 1991)[a].

		Traffic flow (Vehicles/h)		Noise levels (Leq-1 h in dBA)		
Location[b]	Scenario	Baseline	Maximum[c]	Baseline noise levels	Modeled noise levels[c]	Maximum increase (dBA)
Construction Phase						
SR 24	Off-Peak	91	91	62.0	62.0	0.0
	Peak	91	343	62.0		
SR 240	Off-Peak	571	579	70.2	70.6	0.4
	Peak	571	2839	70.2	73.5	3.3
Operation Phase						
SR 24	Off-Peak	91	91	62.0	62.0	0.0
	Peak	300	386	65.7	66.2	1.5
SR 240	Off-Peak	571	582	70.2	70.5	0.3
	Peak	2239	3009	74.1	74.7	0.6

(a) Measured 15 m (49 ft) from the road edge.
(b) SR 24 leads to Yakima; SR 240 leads to the Tri-Cities Area.
(c) Traffic flow and noise estimates varied with NPR technology; the maximum impact from three NPR techniques are shown here.

Table 4.8-4. Monitored levels of noise propagated from outdoor activities at the Hanford Site.[a]

Activity	Average Noise Level	Maximum Noise Level	Year Measured
Water wagon operation	104.5	111.9	1984
Well sampling	74.8 - 78.2		1987
Truck	78 - 83		1989
Compressor	88 - 90		
Generator	93 - 95		
Well drilling, Well 32-2	98 - 102	102	1987
Well drilling, Well 32-3	105 - 11	120 - 125	1987
Well drilling, Well 33-29	89 - 91		1987
Pile driver (diesel, 1.5 m [5 ft] from source)	118 - 119		
Tank farm filter building (9 m [30 ft] from source)	86		1976

(a) Noise levels measured in decibels (dB).

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5.0 Models Used to Estimate Environmental Impacts

Potential and/or realized environmental impacts from nuclear materials at the Hanford Site are evaluated using a wide assortment of computer programs. Most of these programs operate on one or more computer systems from supercomputers to PCs. Most of the programs are well documented and include source-code listings and special instructions for computer users. The use of a modular programming format and restricted use of machine-dependent code also appear to be characteristic of most programs. These features allow for easier modification (or upgrading) of the codes and generally increase program transportability.

A summary of the computer programs described in this chapter is provided in Table 5.1. The programs contain mathematical models that estimate radiation dose or groundwater transport, or health risk of both radionuclides and chemicals.

Radiation dose models are used to calculate dose to selected targets (e.g., organs, individuals, or populations) from all major environmental pathways (i.e., air, soil, water, and food chain). Calculations may be performed for both acute (one-time) and chronic (single years, human lifetimes, or thousands of years) exposures. Three types of radiation doses are generally reported:

- **1-year dose**: the population or individual dose resulting from 1 year of external plus internal exposure

- **committed dose**: the population or individual dose resulting from 1 year of external and internal exposure plus the continued internal dose accumulated from that year's combined inhalation and ingestion exposure

- **accumulated dose**: the population or individual dose (external plus internal) accumulated over a lifetime (usually 50 or 70 years).

The groundwater programs described in this chapter actually include a rather wide assortment of hydrologic and hydrogeochemical models. They are used primarily to simulate subsurface flow (saturated and/or unsaturated) and heat and solute transport through geologic media i.e., soils, fractured rock). Most have been designed to accommodate the unique geologic and climatic features (i.e., flood basalts and arid conditions) that characterize the Hanford Site. They range in sophistication (i.e., size, speed, and cost of operation, graphics capabilities, etc.) from relatively simple one-dimensional models, to more complex two- and three-dimensional models.

Listings for each of the programs appearing in this chapter include 1) a general description with a summary of the key features and primary application of each program, 2) a list of important assumptions and/or limitations that apply to each program, 3) special programming considerations, including the software and hardware compatibility of the current version of the program and, if applicable, a list of supplemental documentation, such as user's guides, 4) a current contact with a name and address of

Table 5.1. Summary of supported computer programs

Program	Category	Description or Primary Use
CAP-88	Radiation Dose	Calculates maximum individual and population dose for chronic air releases of radionuclides
CFEST	Groundwater Transport	Coupled fluid, energy, and solute transport in confined aquifers
GENII	Radiation Dose	Calculates doses from air and water releases of radionuclides via various pathways
MAGNAS3	Groundwater Transport	Three-dimensional model for groundwater flow through porous media
MEPAS	Health Risk	Calculates health risks from radionuclides and chemicals via air and water pathways
MSTS	Groundwater Transport	Three-dimensional thermal and hydraulic transport through variably saturated subsurface environments
ORIGEN2	Radionuclide Inventory	Radionuclide generation and decay
PORFLO-3	Groundwater Transport	Continuum three-dimensional model for fluid flow, heat transfer, and mass transport in porous media
PORFLOW	Groundwater Transport	Multiphase groundwater flow model
RADTRAN 4	Radiation Dose	Health and economic impacts associated with transportation of radioactive materials
RESRAD	Radiation Dose	Calculates site-specific residual radiation contamination guidelines
STOMP	Groundwater Transport	Engineering simulation for evaluating subsurface remediation technologies
TRANSS	Groundwater Transport	One-dimensional groundwater transport model
UNSAT-H	Groundwater Transport	Unsaturated flow model
VAM3DCG	Groundwater Transport	Three-dimensional simulation of moisture movement and solute transport in variably saturated porus media

an individual (or agency) who can provide updated information on a particular program, and 5) a listing of all relevant source documentation for each program. A current contact may not be listed for programs that are not in current usage or in cases in which the principal program author(s) cannot be contacted or is no longer involved with the program. Programs falling into this category have been listed in Appendix A.

In most cases this information has been taken directly from the abstracts, summaries, or introductory sections of the original program documentation. Because many programs undergo frequent revision, material documenting their mathematical models and/or computer implementation is often out of date a short time after it is released. In addition, IBM PC versions of some programs previously only designed to run on mainframes are now available. Therefore, readers are urged to check with the current contacts if in doubt about the capabilities of a particular program.

Finally, the measurement of uncertainty in the evaluation of model performance deserves special mention. Models use mathematical analogues to describe complex physical and/or chemical processes and, for this reason, often provide a greatly simplified view of the "real world." The ability of a model to provide an accurate simulation of a particular process is dependent on many factors. For instance, errors can result from 1) invalid assumptions concerning key model parameters (i.e., boundary conditions, dispersion characteristics, etc.), 2) the use of inappropriate or overly simplistic analogues, 3) calculational errors in the computer codes, and 4) basic inadequacies in the input data. In some cases program performance may be significantly improved by more rigorous sampling, but additional data collection or analysis is often impractical because of time and cost constraints. Serious errors can also arise from model misuse or misinterpretation of program output. Computer programs are designed for specific applications, and users must be aware of their limitations. Consultation with the program author(s) or an experienced user should serve to avoid most problems of this nature.

There are several standard procedures for testing the veracity of mathematical models and the computer programs that use them. Model verification involves comparing program output with results generated by hand calculations. Most models are thoroughly verified during the normal course of program development. Program output may also be compared with results from a related, and usually previously verified, model. This is referred to as benchmarking. The most rigorous test of model uncertainty includes some form of field validation. This involves testing model predictions against actual field data or data obtained from laboratory experiments, which simulate conditions similar to those the program was designed to evaluate. Field validation is not an absolute test of model accuracy, however, and great care should be taken in interpreting the results from these kinds of studies. For the most part, validation studies only provide a limited assessment of model performance (i.e., results may only apply to the conditions defined for the test case). Models used to predict long-term trends (e.g., 10,000-year dose) or impacts resulting from postulated accidents generally cannot be validated. Nevertheless, validation studies provide an additional level of confidence that is highly desirable for engineers, scientists, and management personnel who must make decisions regarding the selection and operation of computer programs used in environmental assessment.

An attempt has been made to acknowledge any verification or validation studies that are cited in the original documentation for each of the programs described in this chapter. Regrettably, unpublished work and/or studies appearing in subsequent or supplemental documents may have been overlooked.

Hanford-specific parameter values for use in these programs may be found in the document put out by the Hanford Environmental Dose Overview Panel (Schreckhise et al. 1993). This document is periodically updated to reflect the latest changes in environmental parameter values. In addition the document gives advice on how to implement the programs for various Hanford environmental and health dose estimates.

5.1 CAP-88

The Clean Air Act Assessment Package - 1988 (CAP-88) is a software package that is currently specified by EPA to implement the atmospheric transport and dose assessment required to demonstrate compliance with the National Emission Standards for Hazardous Air Pollutants (NESHAPs) for radionuclides established by 1990 amendments to the Clean Air Act. CAP-88 stands for Clean Air Assessment Package - 1988, which is an update of the previous EPA AIRDOS and DARTAB codes. The package consists of programs to perform atmospheric dispersion, radiation dosimetry, and risk calculations for chronic radionuclide releases to the atmosphere.

Three versions of the software are currently approved by EPA for demonstrating compliance with the clean air act NESHAPs at DOE facilities – CAP-88, AIRDOS-PC and CAP88-PC. The initial version of the CAP-88 software runs on minicomputer systems (IBM or DEC VAX). The programs supplied with the code package include AIRDOS2, which performs the atmospheric dispersion and deposition calculations and DARTAB2, which performs the dosimetry and risk calculations. The dose and risk factor library supplied with the package consists of output from the RADRISK code. The package also includes several utility programs: PREPAR - a preprocessor that assists the user by converting a FORTRAN namelist input file to the format used by AIRDOS2 (Sjoreen and Miller 1984), PREDA - a preprocessor to create DARTAB2 input data sets from AIRDOS2 output, and RADFMT - a utility to convert RADRISK.BCD (a data file of dose and risk factors for use by DARTAB) to binary format. The AIRDOS-PC and CAP88-PC versions of the software are somewhat simplified versions of the mainframe CAP-88 package that operate on IBM or compatible personal computers using a menu-driven interface.

The CAP-88 software is used to estimate radionuclide concentrations in air; rates of deposition on ground surfaces; ground surface concentrations; and intake rates via inhalation of air and ingestion of vegetables, milk, and meat from airborne releases of up to 36 radionuclides. A modified Gaussian plume equation is used to estimate both horizontal and vertical dispersion of up to 36 radionuclides released from one to six stacks or area sources. Exposure pathways considered by the code include air submersion, inhalation, ground irradiation, immersion in water (deposition into swimming pools), and ingestion of food products produced in the region. Radiation dose to populations and individuals are estimated as the effective dose equivalent using calculated concentrations in environmental media.

The code is distributed with a set of radionuclide-specific data that generally corresponds to the ICRP Publication 30 internal dosimetry models (ICRP 1979-1982) for calculating a 50-year effective dose equivalent. The risk of health effects, including genetic effects and fatal cancers, can also be estimated by organ and radionuclide. Dose and risk factors are generated by the RADRISK code, and are supplied as a text or binary data file with the CAP-88 package.

Assumptions and/or Limitations

- Straight-line Gaussian plume dispersion model used with Pasquill dispersion coefficients calculated using Briggs' equations (Gifford 1976).

- Plume rise (either momentum or buoyancy terms) are calculated by the code, or a pre-calculated value for plume rise may be supplied directly by the user.

- Plume depletion is calculated for both wet and dry deposition.

- Gravitational settling included.

- Both point and area sources are supported.

- Radionuclide concentrations in fresh vegetables, milk, and meat are estimated using the food chain models in NRC Regulatory Guide 1.109.

- Each calculation is limited to 36 nuclides, 20 downwind distances, and 16 directions.

- Atmospheric dispersion and environmental uptake models are appropriate for low-level chronic releases; they are not applicable to short-term or accidental releases of radionuclides.

Programming Considerations

The program is written in FORTRAN IV using the IBM 3081 or 3033 running under the OS/VMS operating system and FORTRAN 77 for the DEC VAX running under VMS. At present an IBM PC version, CAP88-PC, is available from EPA (Parks 1992). The code packages are also distributed by the Oak Ridge Radiation Shielding Information Center (RSIC) as CCC/542A (IBM Mainframe version), CCC/542B (DEC VAX version), CCC/542C (CAP88-PC for IBM and compatible personal computers) and CCC/551 (AIRDOS-PC for IBM and compatible personal computers).

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5.2 CFEST

CFEST provides a multidimensional analysis of coupled fluid, energy, and solute transport and has been used to model nonisothermal events in confined aquifer systems. The latest supercomputer version, CFEST-SC, was developed from an earlier version of the CFEST code (Gupta et al. 1987) and is suitable for operation on a CRAY X-MP[(a)] computer with a UNICOS operating system. This newest version of the code can be installed and run on most unix boxes, e.g., it is currently installed and operating on Silicon Graphics[(b)], Sun Microsystems[(c)], and IBM[(d)] System 6000 workstations. CFEST Version SC-01 was developed by Battelle Memorial Institute, Pacific Northwest Laboratories, Copyright© 1988 by Battelle Memorial Institute "All rights reserved." The previous DEC[(e)] VAX-11/780 virtual memory version of the code was developed under the Department of Energy's (DOE) Civilian Radioactive Waste Management Program (Gupta et al. 1987) by Battelle Project Management Division, Office of nuclear Waste Isolation and Pacific Northwest Laboratory (PNL). The earlier DEC PDP 11/70 version of the CFEST code was developed for the Underground Energy Storage Program managed for the DOE by Pacific Northwest Laboratory (Gupta et al. 1982) and was executed on small computers with a maximum core storage of 16K-32 bit words. CFEST-SC and its predecessors are an extension of the Finite Element Three-Dimensional Ground-Water (FE3DGW) code (Gupta et al. 1979; 1984). Both the FE3DGW code and the various versions of the CFEST code are highly interactive and employ a staged execution structure.

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CFEST-SC is a finite element code for two- or three-dimensional analysis of hydrologic flow, heat transport, and single-constituent solute transport in subsurface confined environments at either the regional or local scale. Only single-phase Darcian flow is considered in this multidimensional analysis package, but either constant or variable density systems can be modeled. While the code is formulated for confined aquifer systems, water table environments can be modeled by an updating of the structure of the surface elements in conjunction with an iterative use of the various subprograms of the CFEST-SC code. In the Cartesian coordinate system the code can simulate flow in a horizontal plane, in a vertical plane, or in a fully three-dimensional region. An option also exists for the axisymmetric analysis of a vertical cross section. The code employs bilinear quadrilateral elements in all two-dimensional analyses and trilinear quadrilateral solid elements in three-dimensional simulations. Both steady-state and transient simulations are possible.

The CFEST-SC code can be used to contribute to a wide variety of projects involving saturated aquifer settings including; 1) regional and local hydrologic characterization, 2) simulation of uncoupled heat transport and contaminant transport with retardation (a linear sorption isotherm) and decay, 3) simulation of coupled heat and contaminant or salinity transport (i.e., density dependent flows), 4) flow path and travel time analyses, and 5) analyses and interpretation of aquifer and tracer field tests. The CFEST-SC code has been applied to several studies involving water flow and contaminant transport in the unconfined and confined aquifers underlying the Hanford Site. These studies have dealt with inverse calibration of the unconfined aquifer model (Jacobson and Freshley 1990), the migration of lead through soils and groundwater (Rhoads et al. 1992), and linking CFEST with a geographic information system (Wurstner and Devary 1993). In an unpublished work Brockhaus (1989) completed a masters thesis at the University of Washington, Seattle, involving a fully three-dimensional CFEST model of the groundwater aquifer system underlying Hanford.

Assumptions and/or Limitations

The CFEST code solves the coupled partial differential equations for pressure, temperature, and solute concentration in a geologic formation. These equations are coupled through the fluid properties of density and viscosity. Porosity is treated as a function of pressure only, i.e., it is not affected by either chemical or energy states. The user has the option to solve one or all of the dependent variables. The following assumptions are incorporated into the equations encoded and the parameters required to execute the CFEST code:

- The flow is transient and laminar (Darcian).

- The permeability and coordinate axes are collinear. The rotation of elements to anisotropy axes is not performed. Finite-element formulations, in general, permit such a rotation. In aquifer problems, horizontal dimensions are far greater than vertical. Therefore, variation between anisotropy axes and the coordinate axes is not significant for regional models. Moreover, field data are generally also limited with respect to anisotropic properties.

- Fluid density is a function of pressure, temperature, and solute concentration.

- Fluid viscosity is a function of temperature and concentration.

- The injected fluid is miscible with the resident aquifer fluids.

- Aquifer properties (i.e., porosity, permeability, and thickness) vary spatially. The thickness variations are nodal while material properties are element constant.

- Hydrodynamic dispersion is a function of fluid velocity.

- Boundary conditions permit natural water movement in the aquifer; heat losses or gains to adjacent formations; and the location of injection, production, and observation wells anywhere within the system.

- The porous medium and fluid are compressible.

- The fluid and porous media are in thermal equilibrium.

- Rock density and heat capacity remain constant.

- Viscous dissipation is negligible with respect to the energy balance.

Verification/Validation Studies

CFEST has been the subject of extensive verification efforts (see Chapters 4 in Cole et al. 1988; Gupta et al. 1987, and Gupta et al. 1982). Solutions have been obtained to 10 problems within three broad categories: 1) flow prediction tests (steady and unsteady drawdown in a confined aquifer, unsteady drawdown in a leaky confined aquifer, uniform regional flow with sources and sinks), 2) energy and solute mass transport verifications (Dirichlet upstream boundary condition, mixed upstream boundary condition, approximate analytical solution to an axisymmetric analysis including radially varying velocity), and 3) energy transport including cap and bedrock conduction (Avdonin's radial problem, Avdonin's linear problem, Gringarten-Sauty problem). Other verification and field applications are discussed by Cole et al. 1988 and Gupta et al. 1987 (i.e., 11 field applications are described in Chapter 6 of Cole et al. 1988). Since it was released in 1988, CFEST-SC has been applied to other field sites in the United States and Japan by Battelle and other consulting engineering firms.

Programming Considerations

CFEST is written in FORTRAN and will compile and execute on a variety of unix computers (e.g., Silicon Graphics, Sun Microsystems, and IBM workstations), on the CRAY X-MP/UNICOS systems, and on DEC VAX/VMS systems.

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5.3 GENII

The Hanford Environmental Dose System (Generation II or GENII) includes the second generation of Hanford environmental dosimetry computer codes. This coupled system of computer codes was developed as part of the Hanford Environmental Dosimetry Upgrade Project and incorporates the internal dosimetry models recommended by the International Commission on Radiological Protection (ICRP) (ICRP 1977; 1979) in updated versions of the environmental pathway analysis models used at Hanford.

The GENII system provides a technically peer-reviewed, documented set of programs for calculating radiation doses from radionuclides released to the environment. The seven linked computer codes and associated data libraries contained in GENII perform essentially the same calculations as found in previous radiation dosimetry programs. The core system of GENII can calculate annual doses, dose commitments, or accumulated doses from acute or chronic releases of radioactive materials to air or water. These calculations were previously supplied by the computer codes KRONIC (Strenge and Watson 1973), SUBDOSA (Strenge et al. 1975), DACRIN (Houston et al. 1974; Strenge 1975), ARRRG (Soldat et al. 1974), FOOD (Baker 1977; Baker et al. 1976), and PABLM (Napier et al. 1980). GENII also can calculate annual doses, dose commitments, and accumulated doses from initial contamination of soil or surfaces, thus incorporating capabilities from PABLM and ONSITE/MAXI (Kennedy et al. 1986, 1987; Napier et al. 1984). A limited biotic transport capability is included that can simulate the results of BIOPORT/MAXI (McKenzie et al. 1985). GENII contains a modified version of the shielding code ISOSHLD (Engle et al. 1966; Simmons et al. 1967) that creates factors relating sources with various geometries to dose rates. An essentially unchanged version of DITTY (Napier et al. 1986) has been added for predicting doses from waste management operations to the public during periods as long as 10,000 years.

The documentation for GENII consists of three volumes. Volume 1 describes the theoretical considerations of the system, including the conceptual diagrams, mathematical representations of the solutions, and descriptions of solution techniques. Volume 2 is a User's Manual providing code structure, user's instructions, required system configurations, and QA-related topics. Volume 3 is a code Maintenance Manual for the serious user, including code logic diagrams, a global dictionary, worksheets and example hand calculations, and listings of the code and its associated data files.

Assumptions and/or Limitations

The assumptions and/or limitations that apply to the GENII system are nearly identical to those described for the first generation dosimetry codes that have been incorporated in this package. Readers are therefore referred to the detailed descriptions of these codes listed separately in Appendix B.

GENII was developed under a QA plan based on the ANSI standard NQA-1 and has undergone two external peer reviews. All steps of the code development have been thoroughly documented and tested. Worksheets and example hand calculations have been provided in the documentation for GENII.

Programming Considerations

GENII is written in FORTRAN and operates on IBM and compatible personal computers (requires a math coprocessor).

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5.4 MAGNAS3

The Multiphase Analysis of Groundwater, Non-aqueous phase liquid And Soluble component (MAGNAS3) is a three-dimensional numerical code that simulates the flow of groundwater, non-aqueous phase liquid (NAPL), and air (or vapor) through porous media in three dimensions. The MAGNAS3 code may be used to simulate the flow of air as a fully active phase, rather than assuming that the air phase is passive. In addition the transport of a dissolved constituent may also be simulated. The transport simulation capability in the code accounts for the advection and hydrodynamic dispersion in all fluid phases, equilibrium sorption, volatization, dissolution, precipitation and first-order degradation. A variety of more simplified flow formulations may be simulated as subsets of the most general fully three-phase modeling approach. Such formulations include pseudo-three-phase (with a passive air phase), two-phase (NAPL-water) flow, and two-phase air-water flow.

Assumptions and/or Limitations

- Flow of the fluid phases is considered isothermal and governed by Darcy's law.
- Each fluid phase is considered slightly compressible (except for gases which are considered compressible), homogeneous and immiscible with the other fluid phases for the flow calculations.
- Transport is governed by Fick's law.
- Adsorption and decay of the solute may be described by a linear equilibrium isotherm and first-order decay rate, respectively.
- Kinetic sorption effects and reversible chemical reactions are not included.

Programming Considerations

MAGNAS3 is proprietary to HydroGeoLogic, Inc. Hence, the software must be obtained from HydroGeoLogic, Inc. Only the executable will be distributed to protect the proprietary interests of HydroGeoLogic, Inc.

The source code was developed and tested on personal computers using the University of Salford and Lahey FORTRAN77 compilers, and has been implemented on IBM, MIPS and SUN workstations with standard FORTRAN77 compilers.

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5.5 MEPAS

The Multimedia Environmental Pollutant Assessment System (MEPAS) is a fully coupled assessment model developed for DOE to estimate public health risks for ranking applications. Developed by Pacific Northwest Laboratory for screening and ranking of environmental problems, MEPAS is designed for site-specific assessments using readily available information to estimate potential health impacts. The model was developed to cover a wide range of potential problems and regulatory issues at DOE sites in various stages of site characterization. MEPAS is a code that can be used to facilitate risk assessments as part of the RI/RA/FS and ER processes. MEPAS is a user-friendly, physics-based, personal computer (PC) model that allows an integrated, site-specific, multimedia environmental assessment using readily available information. MEPAS is based on standard approaches and EPA's general guidance for the RI/FA/FS process. The unique feature of MEPAS is the integration of these computations into a singe-analysis system.

MEPAS is a physics-based risk computation code that integrates source-term, transport, and exposure models. Contaminant source-to-receptor analyses can be conduced through all major transport pathways and exposure routes. The source is a point in space and time where contaminants may be released into the environment. Examples include trenches, leaking underground storage tanks, stacks, landfills, ponds, lagoons, and tile fields. The transport pathway is the environmental medium (e.g., groundwater, surface water, overland, and air) through which a contaminant can migrate from a source. The exposure route is the mode in which a sensitive receptor is exposed to a contaminant. Exposure routes include food-chain considerations and physical contact by humans through inhalation, ingestion, dermal contact, and external dose (for radionuclides only). Risk values are computed for chemical and radioactive carcinogens; while hazard quotients, based on reference doses, are computed for noncarcinogens. For carcinogenic pollutants, estimates of risk to the exposed population are also generated.

A chemical database is provided with the MEPAS methodology to supply all the needed information for each constituent to be evaluated. The MEPAS database (Strenge and Peterson 1989) currently contains chemical properties and constants for nearly 500 chemicals and radionuclides. The database contains information on pollutant identification (name and Chemical Abstract Service registration number) and properties describing physical characteristics (e.g., solubility, vapor pressure, distribution coefficient model parameters), environmental degradation for chemicals (e.g., first-order degradation rates) and decay for radionuclides (e.g., half-lives and decay products [Kocher 1979]), environmental transfer factors, radiological dosimetry factors, and chemical toxicity.

Assumptions and/or Limitations

- Radiation dose factors are based on ICRP Publication 30 internal dosimetry models (ICRP 1979-1988).
- Analyses may be performed or chronic release cases; acute releases are not included in the current version.
- The stack/vent characteristics for point-source, emission-rate calculations include radius, exit temperature and velocity, stack height, and building height for wake effects.
- Wind and mechanical suspension emissions are based on Cowherd et al. (1984).
- Five types of volatilization emissions are based on Thibodeaux (1989) and EPA (1988).
- Transport and dispersion are computed in terms of a sector-averaged Gaussian dispersions model (Busse and Zimmerman 1973; Culkowski 1984).
- Deposition is computed as the sum of outputs from empirical wet and dry deposition algorithms (Van Voris et al. 1984).
- The agricultural ingestion routes include leafy vegetables, other vegetables, meat, and milk using standard exposure pathway models and parameters (NRC 1977, Strenge et al. 1987, Kennedy and Strenge 1992).
- Chemical toxicity is evaluated using the EPA slope factor (for carcinogens) and reference dose (for non-carcinogens) methods.

Programming Considerations

The user interface shell including data capture and storage programs are written in compiled dBASE III Plus, and the MEPAS transport and exposure assessment programs are written in FORTRAN. A new interface shell is under development written in Microsoft Visual Basic. An IBM or 100% compatible PC (with 640-KB RAM, 20-MB hard disk) is required. A math co-processor is not required but will significantly improve the model performance. MEPAS is a file-based application, and all data are stored and exchanged between major components by file input/output to ensure user access to all intermediate data.

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5.6 MSTS

The Multiphase Subsurface Transport Simulator (MSTS) contains a continuum model of air, water, energy, and dilute species conservation. It was written for assessment of the postclosure performance of a potential high-level nuclear waste repository at Yucca Mountain, Nevada, and has been used in barrier studies for the Hanford Site. The fundamental purpose of MSTS is to produce numerical predictions of two-phase (aqueous and gas), two-component (air and water) thermal and hydrologic flow and transport phenomena in variably saturated subsurface environments, which are composed of unfractured and/or highly fractured porous media. Available secondary processes include binary diffusion and vapor pressure lowering.

Transport processes are described by four governing conservation equations (air mass, water mass, energy, and dilute species mass conservation) and associated constitutive functions. These governing conservation equations are discretized for a heterogeneous, anisotropic porous media to algebraic form with an integrated finite difference method. Discretization has been implemented in MSTS for one, two, or three dimensions for two orthogonal computational grid systems; Cartesian or axisymmetric cylindrical. The nonlinear discretized equations are converted to a linear form using a multivariable, residual-based Newton-Raphson iteration technique. Any combination of one, two, or all three of the air, water, and energy equations may be chosen for fully coupled solution to suit the needs of the problem under consideration. The dilute species mass conservation equation is solved sequentially with the coupled equations.

Assumptions and/or Limitations

The following assumptions have been incorporated in the MSTS program:

- The porous media and fluids are a continuation that are at least piecewise continuous.

- Mass advective fluxes from pressure gradients and gravitational body forces follow Darcy's flow equations for aqueous and gas phases.

- Diffusion of components through the gas phase occurs according to Fick's law modified for porous media with soil tortuosity parameters.

- Interphase mass transfer of water between the aqueous and gas phases depends on an assumption of thermodynamic equilibrium.

- Solubilities of air within the aqueous phase follow Henry's law for chemical equilibrium.

- Heat transport within the subsurface environment occurs by thermal diffusion and advection.

- Solid and aqueous phase pathways for thermal diffusion are considered; thermal diffusion through the gas phase is neglected.

- Both sensible and latent advection of thermal energy are considered.

- Only one dilute species, with or without radioactive decay, may be modeled at a time.

- Specie transport through the subsurface environment occurs by diffusion, dispersion, and advection. Species diffusion, dispersion, and advection are combined into a single transport coefficient with a power-law approximation to the exact solution.

- Liquid and water-vapor properties are computed from the International Formulation Committee's steam table functions, and air properties are computed from empirical functions.

- The porous media and the fluid are slightly compressible, permitting the equations to be derived for a nondeforming coordinate system.

- Adsorption and desorption are the only chemical processes described, and equilibrium is assumed.

- Liquid saturation is computed using nonhysteretic empirical functions dependent on gas-aqueous capillary pressures, where the gas-aqueous capillary pressure equals the difference between the gas- and aqueous-phase pressures.

- Liquid relative permeability and gas relative permeability are computed using nonhysteretic empirical functions dependent on liquid saturation.

- A linear isotherm is assumed to describe the adsorption/desorption process.

Programming Considerations

The MSTS Version Beta Release 0002 source code is written in FORTRAN 77, following the American National Standard Institute's (ANSI) standards, and is essentially machine-independent (Environments used to date with MSTS include a CRAY supercomputer, IBM RISC, Sun, Silicon Graphics, and Convex workstations, and IBM PC and Macintosh desktop computers). MSTS features a well-ordered, human-readable input file format which can be generated using the MSTS Graphical Input, a graphical user interface available for the Macintosh environment to provide efficient input file preparation and editing capabilities. Program parameterization is easily accomplished at compilation through a short include file that can be customized to suit the size of the problem to be solved, and the include file can be automatically generated by the MSTS Graphical Input. A restart capability is included in the code. Both a theory manual and a user's guide and reference for the code have been published.

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5.7 ORIGEN2

ORIGEN2 is a versatile point depletion and decay program for use in simulating nuclear fuel cycles and calculating the nuclide compositions of various nuclear materials. The original ORIGEN program (Bell 1973) was designed for use in generating spent fuel and waste characteristics (composition, thermal power, etc.) that would form the basis for the study and design of fuel reprocessing plants, spent fuel shipping casks, waste treatment and disposal facilities, and waste shipping casks. Enhancements appearing in ORIGEN2 include 1) substantial changes to the input/output and control features of the computer program, 2) the inclusion of relatively sophisticated reactor physics calculations for different reactor/fuel combinations, and 3) calculation of spectrum-weighted cross sections and fission product yields for approximately 860 nuclides.

ORIGEN2 uses the matrix exponential method to solve a large system of coupled, linear, first-order ordinary differential equations with constant coefficients. The matrix exponential technique was developed to solve a nonhomogeneous system of equations, which makes it possible for ORIGEN2 to be used in calculating the accumulation of radioactivity in processing plants, in waste disposal operations, and in the environment.

Assumptions and/or Limitations

The following assumptions and/or limitations apply to the ORIGEN2 program:

- Nuclear transmutation and decay are represented as a simultaneous system of linear, homogeneous, first-order ordinary differential equations with constant coefficients.

- The build-up and depletion of nuclides during irradiation is calculated using zero-dimensional (i.e., point) geometry and quasi-one-group neutron cross sections. This means that ORIGEN2 cannot account for spatial or resonance self-shielding effects or changes in the neutron spectrum other than those initially encoded.

- Elemental chemical toxicity used in ORIGEN2 are from Dawson (1974).

Programming Considerations

ORIGEN2 is written in FORTRAN, and versions are available that run on IBM and CDC-compatible computers. A separate user's manual for ORIGEN2 is documented in Croff (1980a,b). An extensive library of nuclear data (half-lives and decay schemes, neutron absorption cross sections, fission yields, disintegration energies, and multigroup photon release data) is included with the program.

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5.8 PORFLO-3

Version 1.2 of the PORFLO-3 computer code embodies a model of steady or transient nonisothermal flow and transport of a dissolved species within a continuous fluid phase in a variably saturated, heterogeneous, anisotropic, fractured porous continuum. The PORFLO-3 code is in some sense an extension of the two-dimensional PORFLO model to three dimensions and variable saturation. However, testing and applications of PORFLO-3 have typically been focused on problems involving isothermal flow and solute transport in the vadose (unsaturated) zone and sedimentary aquifers, whereas the two-dimensional PORFLO model was largely applied to buoyancy driven flow and transport in saturated basalts.

PORFLO-3 simulations generally provide numerical solutions to coupled boundary value problems involving fluid flow, heat transfer, and mass transport. The governing equations are derived from the principles of conservation of mass, momentum, and energy in a stationary control volume. The control volume is assumed to contain a heterogeneous, anisotropic porous medium. Discrete one-dimensional and two-dimensional features of the medium (e.g., fractures, clastic dikes) can be represented in a single effective continuum, or can be distinguished explicitly as lower-dimensional embedded elements. Coupling of the governing equations is through time-varying parameters.

The method of nodal-point integration is used to discretize the governing equations over a nonuniform grid in either cartesian or cylindrical coordinates. The resulting algebraic analogues for one-, two- and three-dimensional problems are solved by a variety of techniques such as the alternating direction implicit method, Choleski decomposition, Point Successive Over-Relaxation, Reduced System Conjugate Gradient, and various other iterative solvers. The gradient and iterative solvers were added particularly for use with the nonlinear equation governing flow in an unsaturated domain, but are applicable to the other governing equations as well. In the coupled mode, the governing equations are solved sequentially at each time step beginning with the fluid flow equation followed by the heat transfer equation and ending with the mass transport equation. The equations can as well be uncoupled and can be solved individually or pairwise.

Assumptions and/or Limitations

The following assumptions are inherent in the PORFLO-3 model:

- The matrix of the porous medium, the infilling fluid phase, and the air phase occupying unfilled void spaces are each assumed to be continuous.

- The porous medium and the fluid are only slightly compressible so that the governing equations can be derived in a fixed (rather than deforming) coordinate system.

- The fluid velocity is small so that inertia terms are negligible and Darcy's law is applicable.
- Variation of fluid density and viscosity with fluid pressure is negligibly small.
- Effective hydraulic conductivity and specific storage are functions of pressure head.
- Variations in the porosity of the porous medium as a result of stress changes have been ignored.
- Heat and mass transport caused by Dufour and Sorret effects, respectively, are negligible.
- Dispersive heat and mass transport can be described by a linear gradient law.
- The porous medium and the fluid are in thermal equilibrium at all times.
- Adsorption and desorption (due to various chemical/physical processes) are assumed to occur rapidly so equilibrium is attained instantaneously.
- A linear isotherm is assumed to describe the adsorption/desorption process.

Verification/Validation Studies

PORFLO-3 has been tested by comparing simulation results with 1) analytic solutions, 2) results from independently developed numerical models, and 3) field data. Independent verification and benchmark testing was first performed for Version 1.0 of PORFLO-3 by Magnuson et al. (1990). A validation exercise for unsaturated flow was conducted with Version 1.1 by Rockhold and Wurstner (1991). The latest formal testing of Version 1.2 (Kline 1993) relies in whole upon tests developed for predecessor versions to demonstrate consistency of results through generations of versions. Other more focused and/or application specific testing has been performed but not specifically documented in a form for publication. Moreover, some significant comparisons of simulated results to field observations are performed in the course of analytical work and are documented unceremoniously in reports of those studies (e.g., Appendix D of WHC 1990; Appendix J of Singleton and Lindsey 1994).

Programming Considerations

PORFLO-3 is written in ANSII Standard FORTRAN77 and operates on a variety of computers. In the past two years, Version 1.2 of PORFLO-3 has been operated successfully on CRAY, IBM RISC, SGI, SUN, 486 and 386 computers at Westinghouse Hanford Company.

Documentation

A users manual for PORFLO-3, independent of any particular computer or operating system, is provided by Runchal et al. (1992). The companion theory manual was prepared for Version 1.0 (Sagar and Runchal 1990), and is applicable to the current Version 1.2.

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Sources

PORFLO-3

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5.9 PORFLOW

Version 2.394gr of the PORFLOW code is a multiphase version of the PORFLOW code and was adapted for the Hanford Grout Performance Assessment. PORFLOW solves a set of coupled transport equations for fluid velocities, pressures, temperature, and concentration of chemical species (up to four) in multi-phase or multi-fluid, variably saturated, fractured or porous media flow.

Assumptions and/or Limitations

These are the same as version 1.2 except that air can be modeled as an active phase, instead of passive.

Programming Considerations

PORFLOW, version 2.394gr, is written in FORTRAN77 and has been implemented on a variety of computers including the Cray and the IBM, SGI, and SUN workstations at Westinghouse Hanford Company.

The code is licensed non-exclusively to Westinghouse Hanford Company by Analytic & Computational Research, Inc. (ACRI) for use in projects sponsored by the United States government. Copies which are provided through ACRI to other government contractors are licensed only by ACRI.

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5.10 RADTRAN 4

RADTRAN 4 is used to evaluate possible health and economic impacts associated with the transportation of radioactive materials. The program uses a combination of meteorological, demographic, health physics, transportation, packaging, and material factors to analyze risks associated with both normal transport (incident-free) and various user-selected accident scenarios. RADTRAN 4 is an update of the RADTRAN 3 computer code discussed in earlier versions of this document.

The RADTRAN 4 program consists of seven submodels 1) a material model that allows users to select basic material parameters including number of curies of each isotope per package, average total photon energy per disintegration, the rate at which released material is deposited on the ground, cloudshine dose factors, the physical character of the waste, half-life, and measures of the radiotoxicity of the dispersed material; 2) a transportation model that considers accident rates for each transportation mode (truck, van, rail, cargo and passenger air, barge, and ship), traffic patterns (fraction of travel occurring on various road types, through different population zones, and under both rush-hour and normal traffic conditions), and basic shipment information (number of crew per vehicle, handling and storage times, duration and number of stops); 3) an accident severity and package release model that classifies accidents according to severity (i.e., fire; crush, impact, and puncture forces) and defines the respirable fraction (particles $< 10\ \mu m$) of airborne material released from packages; 4) a meteorological dispersion model that describes the diffusion of a cloud of aerosolized debris released during an accident; 5) a population distribution model that describes the distribution and relative densities of people in three population zones (rural, suburban, and urban), and in certain specific areas, such as pedestrian walkways, warehouses, and air terminals; 6) a health effects model[a] that evaluates the radiotoxicity of materials in terms of potential for producing acute fatalities, early morbidities, genetic effects, and latent cancer fatalities; and 7) an optional economic model that evaluates the economic impacts connected with surveillance, cleanup, evacuation, and long-term land-use denial activities.

The new features of RADTRAN 4 include the following:

- ability to perform link-by-link route-specific analyses
- addition of an internal radionuclide library

(a) This model does not incorporate BEIR V or ICRP 60 health effects conversion factors. The authors recommend obtaining results as dose risks and applying BEIR V or ICRP 60 health effects conversions to them.

- improved logic for multiple-radionuclide packages
- allows for separate treatment of gamma and neutron exposures
- allows definition of up to 20 accident severity categories.

Perhaps the most significant new feature is the capability to perform route-specific analyses. Up to 40 separate transportation "links" or route segments may be defined. Each link may incorporate route-specific parameters, such as population density, vehicle velocity, accident rate, segment length, transport mode, and zone designation (rural, suburban, or urban). Aggregate data may still be utilized, if desired.

The radiological impacts from transportation accidents are expressed according to the level of consequence, probability of occurrence, and level of risk. A risk figure-of-merit is calculated by summing the products of the probability of each specific accident and its associated level of consequence.

Assumptions and/or Limitations

The following assumptions have been incorporated in the RADTRAN 4 program:

- Dose calculations in the population exposure model assume that the package or shipping cask is a point source or line source of radiation (line-source is used for handlers who work in close proximity to packages; point-source used elsewhere).
- Radioactive materials released from a package during an accident are assumed to be dispersed according to standard Gaussian puff-type models. However, the user may define alternative dispersion factors if desired.
- External radiation exposures from ground contamination are calculated using an infinite plane source model.
- Verification and/or validation studies. Sensitivity analyses have been performed for several applications (i.e., incident-free transportation, vehicular accidents) of the RADTRAN III program and are documented in Neuhauser and Reardon (1986) and Madsen et al. (1986).

RADTRAN 4 is in compliance with ANSI/IEEE 730-89 for software quality assurance and all benchmarking is documented in the accompanying software verification and validation plan.

Programming Considerations

A user's manual (Neuhauser and Kanipe 1992) documents the various options for generating accident scenarios and provides additional instructions for computer operators.

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5.11 RESRAD

The RESRAD program was developed at the Argonne National Laboratory for the United States Department of Energy to compute site specific residual radioactive contamination guidelines. Such guidelines are also known as cleanup criteria. Radiation dose and excess lifetime cancer risks to an individual living in the residual contamination may also be computed.

The program is easy to use, and offers numerous data entry screens. The user must supply site specific parameters or use the default values. The categories and examples of parameters are listed below.

Contaminated Zone Parameters - area and thickness of waste site, decay times

Hydrological Parameters - soil thickness, density, porosity, diffusion coefficients, hydraulic conductivity, evapotranspiration coefficient, precipitation & irrigation amounts, runoff coefficient

Geochemical Parameters - distribution coefficients for each nuclide, leach rates and solubility

External Exposure Parameters - shape factors, shielding factor, exposure time

Inhalation Parameters - inhalation rate, mass loading, dilution length, exposure time

Ingestion Parameters - consumption rates for vegetation, milk, meat, fish, drinking water, and incidental soil, contamination fractions, cattle diet parameters

Radon Parameters - thickness, density, porosity, water content and radon diffusion coefficients for the soil cover and building foundation, also average wind speed and building air exchange rate.

The current version is numbered 5.0, and dated March 11, 1994. The program handles radioactive decay during all steps of the transport and dose processes. This version also enables the user to perform sensitivity studies in which one parameter at a time is calculated at extreme values to see what effect it has on the final dose or concentration guideline.

Assumptions and/or Limitations

The RESRAD program makes a number of simplifying assumptions to speed calculations. The principle ones known to the current contact are shown below.

Radioactive Decay - decay chains are shortened by combining short lived daughters with parents. It is assumed that the daughters will be in equilibrium in the soil and in all food products consumed. This assumption breaks down for the milk pathway, because the milk is consumed within a few days after the cow eats the grass so the decay chains do not have time to return to equilibrium. Plant and animal uptake factors for alpha emitting nuclides differ widely. Of particular concern is the milk pathway for Th-228, the dose from which may be underestimated by an order of magnitude.

Soil-to-Plant Concentration Ratios - Most programs (e.g., GENII and PATHRAE) recognize two separate ratios: one for the plant foliage and the other for the fruits and grains (reproductive portions). The authors of RESRAD combined the two values into one to represent all plant types and structures. This results in small differences with codes such as GENII and PATHRAE.

Site Specific Data - The Hanford Environmental Dose Overview Program (HEDOP) has defined site specific data suitable for most environmental work at the Hanford Site. Other parameters have not been standardized. These should be properly justified and brought to the attention of the HEDOP for general use site wide.

Verification/Validation Studies

The RESRAD program uses standard regulatory models such as are used by the NRC and EPA when evaluating applications. What is unique about RESRAD is the combination of models and the selection of default parameters.

The program has been compared with 6 other programs, including GENII. The results of these comparisons were published informally as a working document for review. The comparisons show large differences in some cases, but the differences are not satisfactorily explained in the document.

Programming Considerations

The RESRAD program is only available for IBM compatible personal computers with a hard disk. The program requires about 2.5 Mbyte on the hard disk. Optional accessories are the math coprocessor and a mouse. The program is easily installed by means of self-extracting archive files.

Documentation

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5.12 STOMP

The Subsurface Transport Over Multiple Phases (STOMP) engineering simulator is currently being developed for the U.S. Department of Energy, Office of Environmental Restoration and Waste Management in conjunction with the Volatile Organic Compounds in Arid Soils Integration Demonstration Program (ARID-ID). The ARID-ID program is directed towards the remediation of sites where the subsurface environment has been contaminated with volatile organic compounds and/or radioactive material. The STOMP engineering simulator provides a variety of capabilities to evaluate subsurface remediation technologies. Specifically the engineering simulator has been designed to provide engineers and scientists with multidimensional analysis capabilities of subsurface flow and transport phenomena for multiple phase and nonisothermal systems in saturated or partially saturated environments. The engineering simulator offers a variable source code configuration, which allows the user to optimize the source code, in terms of execution speed and memory, to the specifics of the subsurface system under consideration. Construction of the variable source code and input files may be performed through an associated interactive graphical user interface.

The engineering simulator employs an integrated-volume finite-difference approach for the physical domain and a backwards Euler approach for the time domain to discretize the governing partial differential conservation equations. Coupled solutions of component mass and energy conservation equations over three immiscible phases (aqueous, gas, and nonaqueous liquid) are possible. Solute transport problems with equilibrium partitioning between four phases (aqueous, gas, nonaqueous liquid, and solid) may be solved for multiple solutes with radioactive decay. The solute transport equations are solved sequentially to the coupled flow and heat transport equations, therefore requiring the assumption of dilute concentrations. Nonlinearities in the discretized coupled flow and heat transport equations are resolved with a Newton-Raphson iteration scheme. Phase appearances and transitions are handled through variable switching schemes. The saturation-relative permeability-pressure constitutive theory for describing both two-phase (water-air) and three-phase (water-oil-air) systems include fluid entrapment and hysteretic effects. The simulator allows a variety of boundary conditions, both internally and externally with respect to the computational domain. The simulator allows computation domains with both permanent and dynamically defined inactive nodes. The simulator currently provides two linear system solvers, a directed banded scheme and an iterative conjugate gradient algorithm.

Assumptions and/or Limitations

The following assumptions have been incorporated into the STOMP engineering simulator:

- Fluid flow through the subsurface follows Darcy's law for porous media.
- Coordinate systems are currently restricted to Cartesian or cylindrical, with plans to extend the capabilities to orthogonal boundary fitted grid systems.
- Thermodynamic and chemical equilibrium exists within a computational cell.
- Dissolution of water and air components within the nonaqueous liquid phase is negligible.
- Diffusion of components and solutes through the aqueous, gas, and nonaqueous phases follows Fick's law modified for porous media.
- Hydrodynamic dispersion of components and solutes functionally depends on the phase pore velocity.
- Gas-phase properties of density, viscosity, and component diffusion coefficients are functions of the gas composition, pressure, and temperature.
- Aqueous- and nonaqueous-phase properties are independent of composition, but dependent on pressure and temperature.
- The saturation-relative permeability-pressure constitutive theory for three-phase systems assumes a wettability order of water-oil-air.
- The aqueous phase is assumed to never totally disappear through a vapor-pressure lowering function.

- All fluid phases and the porous media are considered compressible.
- The rock/soil density and specific heat remain constant.
- Viscous dissipation with respect to the energy equation is neglected.
- The properties of intrinsic permeability and thermal conductivity are collinear with the axes, but may contain anisotropy.

Programming Considerations

STOMP has a variable configuration source code written in FORTRAN 77 with a variety of timing procedural calls for numerous computing platforms.

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5.13 TRANSS

TRANSS contains a simplified groundwater transport model and can be used to estimate the rate of migration of a decaying radionuclide that is subject to sorption governed by a linear isotherm. TRANSS employs simple analytical solutions of the advection-dispersion equation to describe solute movement along a collection of hydrologic streamlines composing a hypothetical streamtube. Local dispersion along a streamtube is treated as a combination of advection and Fickian diffusion, based on an effective dispersion coefficient.

Contaminant release from a source is described in terms of a fraction-remaining curve provided as input information. An option in the program allows for the calculation of a fraction-remaining curve based on four specialized release models 1) constant release rate, 2) solubility-controlled release, 3) adsorption-controlled release, and 4) diffusion-controlled release from beneath an infiltration barrier.

Assumptions and/or Limitations

The following assumptions have been incorporated in the TRANSS program:

- It is assumed that contaminant transport can be represented by a collection of one-dimensional problems defined by the streamlines of a flow field under steady-state conditions.

- Transverse dispersion within a streamtube is assumed to be negligible.

- Travel times along streamlines must be obtained from a prior groundwater flow simulation. *TRANSS is not a predictive program. The program is intended to be used as a scoping tool for estimating the relative influence of transport controlling parameters. Moreover, output estimates depend conditionally on the specific groundwater flow field used as input.*

Verification/validation studies

TRANSS has been verified for a number of sample problems, including well-documented test cases involving the transport of single radionuclides (Simmons and Cole 1985).

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5.14 UNSAT-H

UNSAT-H contains a hydrologic model for simulating water and heat flow in unsaturated soils and is used primarily for assessing the water and energy dynamics of arid sites under consideration for near-surface waste disposal. The program can be used to predict deep drainage (i.e., recharge) as a function of environmental conditions such as climate, soil type, and vegetation. An additional application includes the simulation of various waste management practices, such as placing surface barriers over waste sites.

UNSAT-H employs a one-dimensional, mechanistic model that simulates the dynamic processes of infiltration, drainage, redistribution, surface evaporation, uptake of water from soil by plants, energy exchange between the soil surface and the overlying atmosphere, and the flow of heat within the soil. The mathematical basis of the model is Richards' equation of water flow, Fourier's law of heat conduction, and Fick's law of diffusion. The basic numerical implementation is patterned after the UNSAT model of Gupta et al. (1978).

UNSAT-H uses a fully implicit, finite-difference method for solving the water and heat transport equations. Plant water uptake is introduced as a sink term at each node and is calculated as a function of root density, water content, and potential evapotranspiration. The simulated soil profile can be homogeneous or layered. The boundary conditions can be controlled as either constant head or flux conditions depending on the specific conditions at a given site.

Features of UNSAT-H Version 2.0 that are improvements over the original UNSAT and earlier versions of UNSAT-H include a cheatgrass transpiration function, additional options for describing soil hydraulic properties, consideration of heat and nonisothermal vapor flow, direct calculation of evaporation, and reduction of mass-balance error.

Output from UNSAT-H consists of the following: 1) hourly or daily summaries of water content, water potential, water and heat fluxes, temperature, and plant water use as a function of depth, and 2) cumulative totals of the water and heat balance components (storage, precipitation, evaporation, transpiration, drainage, net radiation, sensible heat, latent heat).

Assumptions and/or Limitations

The following assumptions have been incorporated in the UNSAT-H program:

- Water and heat flows in one dimension.
- Richard's equation, Fourier's law, and Fick's law are valid.
- Liquid water flow is not induced by temperature gradients.
- Air phase is continuous and at constant pressure.
- Soil hydraulic properties are independent of soil temperature.
- Soil hydraulic properties are unique (i.e., not hysteretic).
- Plant growth, development, and transpiration can be described empirically.
- Precipitation and evaporation are not affected by snow cover and snowmelt.

Verification/validation studies

Successful verification tests of the processes of infiltration, redistribution, and drainage have been performed using UNSAT1D (see Simmons and Cole 1985), a precursor model of UNSAT-H. The

UNSAT-H model has been tested using measured field data from the 200-Area closed-bottom lysimeter (Fayer et al. 1986, Appendix B). Fayer and Jones (1990) contains verification tests for the processes of infiltration, redistribution, and drainage and for heat flow. Baca and Magnuson (1990) contains four verification and four benchmark test cases that cover both water and heat flow scenarios in both homogeneous and layered media. Fayer et al. (1992) contains comparisons of model output and field data collected from lysimeters in the 200 Area of the Hanford Site.

Programming Considerations

UNSAT-H Version 2.0 is written in VAX FORTRAN Version 4.7 and runs under the VAX/VMS Version 4.7 Operating System. The UNSAT-H Version 2.0 code has been modified to run on DOS and UNIX machines also. This extended version is called Version 2.01.

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5.15 VAM3DCG

The Variably Saturated Analysis Model in 3 Dimensions with Preconditioned Conjugate Gradient Matrix Solvers (VAM3DCG) contains a continuum model of water and dilute species conservation. The VAM3DCG program is proprietary to HydroGeoLogic, Inc. It was originally developed for the U.S. Nuclear Regulatory Commission.

VAM3DCG is a three-dimensional, finite element code developed to simulate moisture movement and solute transport in variably saturated porous media. The code is capable of simulating a wide range of conditions commonly encountered in the field. Simulations can be performed efficiently for fully three-dimensional, two-dimensional, or axisymmetric problems. Both flow and transport processes are handled concurrently or sequentially. Material heterogeneities and anisotropy are handled by taking advantage of the finite element approach. Efficient matrix computation and solution schemes are employed in conjunction with simple rectangular prism elements or hexahedral orthogonal curvilinear elements, to analyze problems involving highly nonlinear, hysteretic/nonhysteretic soil moisture characteristics. Many types of boundary conditions can be accommodated including: 1) water table conditions, 2) atmospheric conditions associated with seepage faces, evaporation and nonponding infiltration, 3) water uptake by plant roots, 4) vertical recharge of the water table, and 5) pumping and injections wells.

Assumptions and/or Limitations

The following assumptions have been incorporated in the VAM3DCG program:

- Water is the only flowing fluid phase (i.e., the air phase is assumed to be inactive).
- Flow of the fluid phase is considered isothermal and governed by Darcy's law.
- The fluid is considered slightly compressible and homogeneous.
- Transport in the porous medium system is governed by Fick's law. The hydrodynamic dispersion coefficient is defined as the sum of the coefficients of mechanical dispersion and molecular diffusion. The medium dispersivity is assumed to correspond to that of an isotropic medium, where α_L and α_T are the longitudinal and transverse dispersivities.
- Adsorption and decay of the solute may be described by a linear equilibrium isotherm and a first order decay rate, respectively.
- In performing a variably saturated flow analysis, the code handles only single-phase flow (i.e., water) and ignores the flow of a second phase (i.e., air or other nonaqueous phase) which, in some instances, can be significant.
- Flow and transport in fractures are not taken into account.
- The code does not take into account kinetic sorption effects and/or reversible chemical reactions which, in some instances, can be important.

Programming Considerations

VAM3DCG is proprietary to HydroGeoLogic, Inc. Hence, the software must be obtained from HydroGeoLogic, Inc. Only the executable will be distributed to protect the proprietary interests of HydroGeoLogic, Inc. Code alterations to meet special needs, and resizing of parameters and arrays within the code, must be negotiated with HydroGeoLogic, Inc.

There is no graphical user interface for VAM3DCG; it relies on a highly formatted input file developed by the user using a text editor and the standards set forth in the documentation to control the code's operation and to provide input parameter values. A grid generator utility (also proprietary to HydroGeoLogic, Inc.) is in development for Unix environments and is of limited use in preparation of input grids and assignment of boundary conditions.

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6.0 Statutory and Regulatory Requirements

The Hanford Site is owned by the U.S. Government and is managed by the U.S. Department of Energy (DOE). It is the policy of the DOE to carry out its operations in compliance with all applicable federal laws and regulations, state laws and regulations, presidential executive orders, and DOE orders. Environmental regulatory authority over the Hanford Site is vested both in federal agencies, primarily the U.S. Environmental Protection Agency (EPA), and in Washington State agencies, primarily the Washington Department of Ecology (Ecology) and the Washington Department of Health (DOH). Significant environmental laws and regulations are discussed in this chapter. First, major federal environmental laws are listed; then, significant applicable federal and state regulations are discussed; and finally, DOE orders, permits, and some specific regulations for the environmental protection of the public are discussed.

(The following introduction [italicized text] is intended to be explanatory for persons writing Chapter 6.0 for a Hanford Site Environmental Impact Statement [EIS], but is not intended to be included in the EIS.)

Introduction

The regulations of the Council on Environmental Quality (CEQ) in the Code of Federal Regulations (CFR) at 40 CFR 1500-1508 implement the National Environmental Policy Act (NEPA) and set forth requirements for the preparation of environmental documentation by federal agencies. The CEQ regulations develop the NEPA process and focus on the EIS. The CEQ regulations identify the types of actions proposed by a federal agency that require preparation of an EIS, prescribe the content of an EIS, and identify actions and other environmental reviews that must or should be undertaken by the federal agency in preparing and circulating an EIS. In general, an EIS must be prepared by a federal agency for any major federal action significantly affecting the quality of the human environment (40 CFR 1502.3).

A specific requirement in the CEQ regulations (40 CFR 1502.25) is that the EIS must list "all Federal permits, licenses, and other entitlements which must be obtained in implementing the proposal." There is, however, no requirement in the CEQ regulations that the EIS must list or discuss applicable environmental laws and regulations. Nevertheless, applicable environmental laws and regulations have been discussed in recent Hanford Site EISs, and Chapter 6.0 of these EISs has evolved into a chapter on "Statutory and Regulatory Requirements." Given the large number of applicable environmental regulations and the rapidly changing character of environmental regulation, this practice is likely to continue.

The purpose, then, of this document is to present a "reference" Chapter 6.0 that can be used in the preparation of future Hanford Site EISs. The intent here is to present a rather inclusive discussion of federal and state environmental laws, regulations, and permits that are applicable to activities at the Hanford Site. The information in this chapter can then be adapted to any future Hanford Site EIS simply by deleting the irrelevant parts and by adding some specificity with respect to the proposed action. It is also intended that this document be revised on a regular basis because of the rapidly *changing nature of federal environmental law and regulation, particularly because of the rapidly emerging (and thus still not fully developed) regulation of federal facilities by states.*

It should be noted that environmental standards and permit requirements usually appear in regulations and not in the laws themselves. Thus, more emphasis is placed on regulations and less on laws in this document.

Federal and State Environmental Laws

Environmental regulation of federal facilities is governed by federal law. Most major federal environmental laws now include provisions for regulation of federal activities that impact the environment. The activity to be regulated is usually an activity being carried out by an agency of the executive branch. The federal environmental law will also designate a specific agency, such as the EPA or the U.S. Nuclear Regulatory Commission (NRC), as the regulator, or the law will permit self-regulation. In addition, federal laws may provide for the delegation of the environmental regulation of federal facilities to the states or may directly authorize the environmental regulation of federal facilities by the states through waivers of sovereign immunity. At Hanford, all these situations apply in varying degrees: the EPA has regulatory authority over Hanford facilities (where not authorized or delegated) and the NRC may have some future regulatory authority over some future Hanford facilities; the EPA has delegated regulatory authority to, shares regulatory authority with, or is in the process of delegating regulatory authority to, the state of Washington; and the state of Washington asserts its own independent regulatory authority under federal waivers of sovereign immunity.

As a legal matter at Hanford, applicable federal and state environmental standards must be met. As a practical matter, differences in language between federal law and the pursuant state laws and regulations may result in some differences in applicability and interpretation. These prospective events, however, need not concern us here. Guidance on specific applicability should be obtained from the DOE Richland Operations Office legal counsel.

Citation of Laws and Regulations

Laws and regulations may be cited both by their name and by their location in the appropriate document. Federal laws are most often cited as a public law (Pub. L. or PL) or by their location in the United States Code (USC). Section numbers differ between the two, so it must be understood which is being cited. Federal regulations appear in the CFR. Washington State laws are most often cited by their location in the Revised Code of Washington (RCW), and Washington State regulations are cited by their location in the Washington Administrative Code (WAC). Announcements of proposed and final federal regulations appear in the Federal Register (FR). Announcements of proposed and final Washington State regulations appear in the Washington State Register (WSR).

Specific Federal Laws Cited in the CEQ Regulations

Four federal laws are specifically cited in the CEQ regulations and deserve mention here. These are Section 309 of the Clean Air Act (CAA) (42 USC 7609), the Fish and Wildlife Coordination Act (16 USC 661 et seq.), the National Historic Preservation Act (NHPA) (16 USC 470 et seq.), and the Endangered Species Act (16 USC 1531 et seq.). Section 309 of the CAA directs the EPA to review and *comment on the environmental impacts of federal activities, including actions for which EISs are prepared. In addition to commenting on EISs, EPA rates every draft EIS prepared by a federal agency. The fact that EPA rates EISs should be known by the EIS preparers so that the EIS will be prepared in such a fashion as to avoid an unfavorable rating. EPA's comments on the draft EIS are answered in the final EIS. The other three federal laws are often discussed in the chapter on the affected environment, rather than in the chapter on statutory and regulatory requirements. They should be discussed somewhere in the EIS and are discussed here for completeness.*

6.1 Federal Environmental Laws

Significant federal environmental laws applicable to the Hanford Site include the following:

- NEPA (42 USC 4321 et seq.)
- CAA as amended by the Clean Air Act Amendments (CAAA) of 1990 (42 USC 7401 et seq.)
- Clean Water Act (CWA) (33 USC 1251 et seq.)
- Safe Drinking Water Act (SDWA) (42 USC 300f et seq.)
- Resource Conservation and Recovery Act (RCRA) as amended by the Hazardous and Solid Waste Amendments (42 USC 6901 et seq.)
- Federal Facilities Compliance Act (FFCA) (PL 102-386)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act (SARA) (42 USC 9601 et seq.)
- Toxic Substances Control Act (TSCA) (15 USC 2601-2671)
- Endangered Species Act (16 USC 1531-1534)
- Fish and Wildlife Coordination Act (16 USC 661-666c)
- Bald and Golden Eagle Protection Act (16 USC 668-668d)
- Migratory Bird Treaty Act (16 USC 703-711)
- NHPA (16 USC 470-470w-6)
- Archaeological Resources Protection Act (ARPA) (16 USC 470aa-470ll)
- Archaeological and Historic Preservation Act (16 USC 469-469c)
- American Antiquities Act (16 USC 431-433)

- American Indian Religious Freedom Act (42 USC 1996)

- Native American Graves Protection and Repatriation Act (25 USC 3001 et seq.)

- Comprehensive Conservation Study of the Hanford Reach of the Columbia River (PL 100-605).

In addition, the Atomic Energy Act (AEA) (42 USC 2011 et seq.), the Low-Level Radioactive Waste Policy Act (LLWPA) (42 USC 2021b et seq.), and the Nuclear Waste Policy Act (NWPA) (42 USC 10101 et seq.), while not environmental laws per se, contain provisions under which environmental regulations applicable to the Hanford Site may be or have been promulgated.

6.2 Federal and State Environmental Regulations

Activities of the federal government are ordinarily not subject to regulation by the states, unless specific exceptions are created by Congress. Exceptions with respect to environmental regulation have been created by Congress and provisions in several federal laws give to the states specific authority to regulate federal environmental activities. These waivers (or partial waivers) of sovereign immunity appear in Section 118 of the CAA, Section 313 of the CWA, Section 1447 of the SDWA, Section 6001 of RCRA, and Section 120 of CERCLA/SARA. The FFCA is an amendment to RCRA that makes the RCRA waiver of sovereign immunity more explicit. At the present time, most Washington State programs with respect to the environmental regulation of Hanford facilities are coordinated with EPA Region 10.

Federal and state environmental regulations that may apply to DOE operations at the Hanford Site have been promulgated under the CAA, CWA, SDWA, RCRA, CERCLA, SARA, AEA, LLWPA, NWPA, under other federal statutes, and under relevant state statutes. The CAA amendments of 1990 will result in extensive revisions of federal and state air quality regulations. Specifically, a large list of hazardous air pollutants will be brought under regulation and a more uniform state regulatory and permitting system under state implementation plans will result. Also, federal and state regulations relating to hazardous waste management continue to be promulgated under RCRA at a rapid rate.

Several of the more important existing federal and state environmental regulations are discussed briefly below. These regulations are grouped according to areas of environmental interest.

6.2.1 Air Quality

- 40 CFR 50, "National Primary and Secondary Ambient Air Quality Standards." EPA regulations in 40 CFR 50 set national ambient air quality standards (NAAQSs) for air pollutants including sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. These standards are not directly enforceable; but other, enforceable regulations are based on these standards.

- 40 CFR 51-52, State Implementation Plans (SIPs). EPA regulations in 40 CFR 51-52 establish the requirements for SIPs and record the approved plans. The SIPs are directed at the control of emissions from stationary sources and include state permits (see 40 CFR 70 below).

- 40 CFR 60, "Standards of Performance for New Stationary Sources." EPA regulations in 40 CFR 60 provide standards for the control of the emission of pollutants to the atmosphere. Construction or modification of an emissions source in an attainment area formerly required a prevention of significant deterioration of air quality (PSD) permit under 40 CFR 52. These permits will in the future become part of EPA's or the state's comprehensive air permit program (see 40 CFR 70 below).

- 40 CFR 61, "National Emission Standards for Hazardous Air Pollutants," (NESHAP); also 40 CFR 61 Subpart H, "National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities." EPA hazardous emission standards in 40 CFR 61 provide for the control of the emission of hazardous pollutants to the atmosphere, and standards in 40 CFR 61 Subpart H apply specifically to the emission of radionuclides from DOE facilities. Approval to construct a new facility or to modify an existing one may be required by these regulations. EPA has not yet delegated this approval authority to the state of Washington for the Hanford Site, but this delegation is likely to occur under the EPA's consolidated air permit program (see 40 CFR 70 below). The brief list of hazardous air pollutants presently regulated under 40 CFR 61 will be expanded pursuant to the CAA amendments of 1990 and may include the 189 hazardous air pollutants listed in the amendments.

- 40 CFR 70, "State Operating Permit Programs." These regulations provide for the establishment of comprehensive state air quality permitting programs that will replace the existing fragmented programs. All major sources of air pollutants including hazardous air pollutants will be covered. Changes may be made in WAC 173-400 through 173-495 and in WAC 246-247 (see below).

- WAC 173-400 through 173-495, Washington State Air Pollution Control Regulations; General Regulation 80-7, Benton County Clean Air Authority. Ecology air pollution control regulations, promulgated under the Washington CAA (RCW 70.94), appear in WAC 173-400 through 173-495. These regulations include emission standards, ambient air quality standards, and the new standards in WAC 173-460, "Controls for New Sources of Toxic Air Pollutants." The state of Washington has delegated much of its authority under the Washington CAA to the Benton County Clean Air Authority.

- WAC 246-247, "Radiation Protection--Air Emissions." Washington DOH regulations in WAC 246-247 contain standards and permit requirements for the emission of radionuclides to the atmosphere from DOE facilities based on Ecology standards in WAC 173-480, "Ambient Air Quality Standards and Emission Limits for Radionuclides."

6.2.2 Water Quality

- 40 CFR 121, "State Certification of Activities Requiring a Federal License or Permit." These regulations provide for state certification that any activity requiring a federal water permit, i.e., a National Pollutant Discharge Elimination System (NPDES) permit or a discharge of dredged or fill material permit, will not violate state water quality standards.

- 40 CFR 122, "NPDES." EPA regulations in 40 CFR 122 (and also in 40 CFR 125 and 129) apply to the discharge of pollutants from any point source into waters of the United States. These regulations also now apply to the discharge of storm waters and the discharge of runoff waters from construction areas over 2 ha (5 acres) in size into waters of the United States. NPDES permits may be required by 40 CFR 122. EPA has not yet delegated to the State of Washington the authority to issue NPDES permits at the Hanford Site.

- 40 CFR 141, "National Primary Drinking Water Regulations." EPA drinking water standards in 40 CFR 141 apply to Columbia River water at community water supply intakes downstream of the Hanford Site.

- 40 CFR 144-147, "Underground Injection Control Program" (UIC). EPA regulations in 40 CFR 144-147 apply to the underground injection of liquids and wastes and may require a permit for any underground injection. In Washington State, the EPA has approved Ecology regulations in WAC 173-218, "Underground Injection Control Program," to operate in lieu of the EPA program. The Ecology regulations provide standards and permit requirements for the disposal of fluids by well injection.

- 10 CFR 1022, "Compliance with Floodplain/Wetlands Environmental Review Requirements." DOE regulations in 10 CFR 1022 apply to DOE activities that are proposed to take place either in wetlands or in floodplains.

- 33 CFR 322-323, 40 CFR 230-233, Corps of Engineers Permits. Structures in the Columbia River and work in the Columbia River, as well as the discharge of dredged or fill material into the Columbia River, require Corps of Engineers permits under these regulations.

- WAC 173-160. Under WAC 173-160, DOE provides notification to Ecology for water-well drilling on the Hanford Site.

- WAC 173-216, "State Waste Discharge Permit Program." Ecology regulations in WAC 173-216 establish a state permit program for the discharge of waste materials from industrial, commercial, and municipal operations into ground and surface waters of the state. Discharges covered by NPDES or WAC 173-218 permits are excluded from the 216 program. DOE has agreed to meet the requirements of this program at the Hanford Site for discharges of liquids to the ground.

- RCW 75.20.100, "Hydraulic Projects Act," WAC 220-110. As a matter of comity, DOE will obtain hydraulic project approval from the State Departments of Fisheries and Wildlife to construct any form of hydraulic project or perform work that will divert, obstruct, or change the natural flow of the Columbia River.

- WAC 332-30, River Bottom Lease. Where applicable, DOE will obtain an aquatic land-use lease or permit from the Washington Department of Natural Resources for the placement of structures in the Columbia River on lands owned by the state of Washington. DOE owns most of the riverbed along the Hanford Site to the line of navigation.

6.2.3 Solids

- 40 CFR 260-268 and 270-272, "Hazardous Waste Management." EPA RCRA regulations in 40 CFR 260-268 and 270-272 apply to the generation, transport, treatment, storage, and disposal of hazardous wastes (but not to source, by-product, or special nuclear material, i.e., not in general to radioactive wastes), and apply to the hazardous component of hazardous radioactive mixed wastes (but not to the radioactive component) owned by DOE. RCRA regulations require treatment of many hazardous wastes before they can be disposed of in landfills (land disposal restrictions). RCRA permits are required for the treatment, storage, or disposal of hazardous wastes. The regulations also require cleanup (corrective action) of any RCRA facility from which there is an unauthorized release before a RCRA permit may be granted. Most of the authority to administer the RCRA program has been delegated by EPA to the state of Washington, except for corrective action.

- 40 CFR 280-281, Underground Storage Tanks. EPA regulations in 40 CFR 280-281 apply to underground storage tanks and may require permits for new and existing tanks containing petroleum or substances regulated under CERCLA (except for hazardous wastes regulated under RCRA). EPA has authorized Washington State to administer this program under RCW 90.76 and WAC 173-360.

- 40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan." EPA CERCLA regulations in 40 CFR 300 apply to the cleanup of inactive hazardous waste disposal sites, the cleanup of hazardous substances released into the environment, the reporting of hazardous substances released into the environment, and natural resource damage assessments. On November 3, 1989, the Hanford Site was placed on the EPA's National Priorities List (NPL). Placement on the list requires DOE, in consultation with EPA and Washington State, to conduct remedial investigations and feasibility studies leading to a record of decision on the cleanup of inactive waste disposal sites at Hanford. Standards for cleanup under CERCLA are "applicable or relevant and appropriate requirements" (ARARs) which may include both federal and state laws and regulations. In anticipation of Hanford's being placed on the NPL, DOE, EPA, and Ecology signed the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) on May 15, 1989. This agreement describes the cleanup responsibilities and authorities of the three parties under CERCLA (and RCRA), and also provides for permitting of the treatment, storage, and disposal of hazardous wastes under RCRA. A revised Tri-Party Agreement was signed on January 25, 1994. These revisions were occasioned by substantial changes in plans for dealing with high-level wastes stored in underground tanks at Hanford.

- WAC 173-303, "Dangerous Waste Regulations." The EPA has authorized the State of Washington through Ecology to conduct its own dangerous waste regulation program in lieu of major portions of the RCRA interim and final permit program for the treatment, storage, and disposal of hazardous wastes. Ecology is also authorized to conduct its own program for the hazardous portion of radioactive-mixed wastes. However, EPA has retained its authority to administer those sections of the hazardous waste program mandated by the Hazardous and Solid Waste Amendments to RCRA, specifically corrective action. The state regulations include both standards and permit requirements.

6.2.4 Species Protection

- 50 CFR 10-24, 222, 225-227, 402, and 450-453, Species Protection Regulations. Regulations of the Endangered Species Act, the Bald and Golden Eagle Protection Act, and the Migratory Bird Treaty Act in 50 CFR 10-24 apply to the protection of these species on the Hanford Site. Regulations in 50 CFR 222, 225-227, 402, and 450-453 apply to endangered or threatened species. In addition, the Fish and Wildlife Coordination Act requires consultation with the U.S. Fish and Wildlife Service if any body of water over 4 ha (10 acres) in size is to be modified by a federal agency for any purpose. The purpose of this consultation is to prevent loss and damage to wildlife resources.

6.2.5 Historic and Cultural Resource Preservation

- 36 CFR 800, 25 CFR 261, 43 CFR 3, and 43 CFR 7, Historic Preservation Regulations. Requirements of the NHPA in 36 CFR 60 and 36 CFR 800; the American Antiquities Act in 25 CFR 261 and 43 CFR 3; the Archaeological Resources Protection Act and the American Indian Religious Freedom Act in 43 CFR 7; and the Native American Graves Protection and Repatriation Act apply to the protection of historic and cultural properties, including both existing properties and those discovered during excavation and construction.

6.2.6 Land Use

The Comprehensive Conservation Study of the Hanford Reach of the Columbia River (PL 100-605) required the Secretary of the Interior, in consultation with the Secretary of Energy, to conduct a study of the Hanford Reach of the Columbia River that included identification and evaluation of geologic, scenic, historic, cultural, recreational, fish, wildlife, and natural features of the Hanford Reach. The Secretary of the Interior was also directed by Congress to examine alternatives for the preservation of these features. A final study report was published in June 1994: *Hanford Reach of the Columbia River, Comprehensive River Conservation Study and Environmental Impact Statement*. This study may lead to recommendations to Congress that the Hanford Reach of the Columbia River be designated a wild or scenic river under the Wild and Scenic River Act.

6.2.7 Other

- 40 CFR 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes." EPA regulations in 40 CFR 191 provide environmental standards for the management, storage, and disposal of spent nuclear fuel, high-level radioactive wastes, and transuranic radioactive wastes at high-level or transuranic waste disposal sites.

- 40 CFR 700-799, TSCA Regulations. EPA's regulations in 40 CFR 700-799 implement TSCA and, in particular, regulate polychlorinated biphenyls and dioxins and partially regulate asbestos.

- 40 CFR 1500-1508, Regulations of the CEQ that implement NEPA. The CEQ regulations in 40 CFR 1500-1508 provide for the preparation of environmental documentation on any federal action impacting the environment, and require federal agencies to prepare an EIS on any major federal action significantly affecting the quality of the human environment.

- 10 CFR 1021, "Compliance with the National Environmental Policy Act." DOE regulations in 10 CFR 1021 implement the NEPA and the Council on Environmental Quality's NEPA regulations in 40 CFR 1500-1508.

- 49 CFR 171-179, "Hazardous Materials Regulations." Department of Transportation regulations in 49 CFR 171-179 apply to the handling, packaging, labeling, and shipment of hazardous materials offsite, including radioactive materials and wastes.

6.3 DOE Orders

The most significant DOE orders with respect to environmental compliance at Hanford are those in the 5400 series. These orders cover environmental protection, safety, and health protection standards; hazardous and radioactive-mixed waste management; cleanup of retired facilities; safety requirements for the packaging and transportation of hazardous materials; safety of nuclear facilities; radiation protection; and other standards for the safety and protection of workers and the public. Regulations and standards of other federal agencies and regulatory bodies, as well as other DOE orders, are incorporated by reference into DOE orders. Some DOE orders related to the environment are being prepared for promulgation as regulations in the CFR. Other DOE orders that are important with respect to environmental compliance include DOE Order 5820.2A, "Radioactive Waste Management."

6.4 Permits

The DOE holds an NPDES permit from EPA Region 10 for the discharge of nonradioactive liquids to the Columbia River. On June 28, 1985, the DOE applied for renewal of this permit. The original permit is still in effect pending renewal. An application has been filed for a treatment facility for process wastewater (1325-N), and an NPDES permit was issued in October 1994 for the 300 Area Treated Effluent Disposal Facility.

The Washington Department of Ecology issued a permit to DOE under WAC 173-216 for the 200 Area Treated Effluent Disposal Facility in April 1995. A permit for additional discharges to the ground in the 200 Area under WAC 173-216 was issued by Ecology in June 1995 for the Effluent Treatment Facility. The DOE holds a PSD permit from EPA Region 10 for the discharge of oxides of nitrogen to the atmosphere from the Plutonium Uranium Extraction (PUREX) and Uranium Oxide Plants.

The DOE holds approvals for construction of air emission facilities and approvals of alternate air emission limits issued by the Benton County Clean Air Authority.

The DOE received a Radioactive Source Registration permit from the Washington Department of Health on August 15, 1993, for radioactive emissions from Hanford Site operations.

Federal and state air quality permits will be consolidated in the future under the CAA amendments of 1990. A permit application was submitted to the appropriate agencies in May 1995.

The DOE holds interim status for the operation of hazardous waste management facilities by virtue of having submitted a RCRA Part A application to EPA on November 18, 1980. On November 6, 1985, the DOE submitted a RCRA Part B application to EPA Region 10 and to the WDOE for the storage, treatment, and disposal of hazardous wastes at Hanford. Supplemental and revised RCRA applications have been submitted either to Ecology, to the EPA, or to both as appropriate. A final status permit covering several units at the Hanford Site was issued in August 1994. This permit will be amended over a period of years to add additional interim status units to the permit. A wastewater pilot plant research, development, and demonstration (RD&D) permit has also been issued to the Hanford Site.

DOE has asserted a federally reserved water withdrawal right with respect to its Hanford operations. Current activities use water withdrawn under the DOE's federally reserved water right.

6.5 Environmental Standards for Protection of the Public

Numerical standards for protection of the public from releases to the environment have been set by the EPA and appear in the CFR.

Standards in 40 CFR 61.92 apply to releases of radionuclides to the atmosphere from DOE facilities and state that:

> Emissions of radionuclides (other than radon-220 and radon-222) to the ambient air from Department of Energy facilities shall not exceed those amounts that would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/yr.

Standards in 40 CFR 141.16 apply indirectly to releases of radionuclides from DOE facilities (and also non-DOE facilities) to the extent that the releases impact community water systems:

> The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water shall not produce an annual dose equivalent to the body or any internal organ greater than 4 millirem/year.

Also, maximum contaminant levels in community water systems of 5 pCi/L of combined radium-226 and radium-228, and maximum contaminant levels of 15 pCi/L of gross alpha particle activity, including radium-226 but excluding radon and uranium, are specified in 40 CFR 141.

40 CFR 141 also specifies maximum concentrations of some chemical contaminants in drinking water, including arsenic, lead, mercury, nitrate, and some organic compounds.

EPA regulations in 40 CFR 264 contain numerical standards for protection of the public from releases of hazardous wastes from hazardous waste disposal sites.

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